COOLEY'S SERIES

PHYSICAL SCIENCE

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NATURAL PHILOSOPHY

FOR

COMMON AND HIGH SCHOOLS.

BY

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PREFACE.

THE great aim of this little book is to present the most elementary facts of Natural Philosophy, in such a way as to exercise the child constantly in observing phenomena and in drawing inferences from what he observes.

Whenever a child is old enough to ask such questions, as, "What makes the thunder," or, "Where does the rain come from," or to exclaim "How pretty the clouds are this evening," it is old enough to begin the study of natural philosophy. When such questions are asked the mind is awake to see the phenomena of nature, and is ready to receive instruction. They show the presence of a desire to know, and the absence of power to learn without assistance; and in this way they lead us to believe that the time has come when the work of instruction should begin.

Moreover, the study of natural philosophy is easy, and interesting to young pupils, because, when properly presented, it brings new sights to the eye, and new sounds the ear, in a way to be especially pleasant to children. The simplest experiments awaken enthusiasm in the mind of a child, and such as he may be able to repeat by himself are the source of the greatest delight.

This study is not only easy and interesting, it is also in the highest degree beneficial to the young, partly because of the valuable facts it imparts, but even more on account of the mental power it developes. The object of primary education should be to discipline the senses to habits of quick and accurate observation, and the mind to the habit of forming correct judgments from facts which the senses reveal. Natural Philosophy furnishes abundant materials of the most excellent kind, by means of which these objects may be accomplished. There are curious motions, beautiful colors and harmonious sounds, together with numerous other phenomena, which can be easily presented in the form of simple experiments, by which the skilful teacher can cultivate the power of the senses to furnish correct impressions, and at the same time develope the power of basing accurate judgments upon the impressions received. In a word, this study when properly presented is eminently fitted to teach even young pupils *how to gain knowledge for themselves* by observing events.

To this end, the following plan ought to prevail in presenting elementary facts. An easy experiment or some phenomenon of common occurrence, is to be introduced and the attention of the child directed to certain appearances and conditions, after which he may be called upon to notice the truth which these appearances suggest. A concise and accurate statement of the fact or principle itself, in form to be easily remembered, may finally complete the investigation.

Many of the experiments are such as pupils can make for themselves; let them be encouraged to do so; if they are,

they will soon be bringing to the notice of the teacher, others which the text does not describe, and if the teacher will visit such efforts with marks of especial notice or reward he will soon find an enthusiasm in his class, which will make the pursuit of this study delightful and profitable to the end.

Another feature of this little book, which, it is believed, will commend it to the favor of both pupil and teacher, is the system of questions which runs through it. Every important topic in the discussion of each subject is introduced by a *question*, instead of by a *formal title*, as is customary. These questions will prove to be excellent guides, and really very important helps to the young pupil. The teacher will also find them serviceable in conducting the exercises of the class room, to which they are especially adapted, by being in immediate connection *with the text*, and in bold type *easily caught by the eye*, instead of at the bottom of the page or the back of the book, in fine print and compact lists. The eye catching them quickly, is not confined to the book; their use, therefore, will not be at the sacrifice of the vivacity and vigor of the exercise.

Albany, 1871.

NATURAL PHILOSOPHY.

PROPERTIES OF MATTER.

Describe the experiment with cochineal.—If, to try an easy experiment, we take a single grain weight of cochineal, and dissolve it in as much as a thimbleful of water, and then pour this small quantity into a gallon of clear water, the whole gallon will receive a beautiful crimson color.

Into how many pieces has the grain of cochineal been divided?—Now a gallon of water is said to contain as many as 60,000 drops, and to color a single drop, all through, will take as many as 100 little particles of cochineal. If this is true, then the grain of cochineal must be divided into not less than *six millions of pieces!*

Can other bodies be divided?—If an apple be cut into 100 pieces, each piece will of course be very small indeed, but yet it will not be so small that it can not be divided into pieces smaller yet.

The blow of a hammer may break a pane of glass into a thousand parts, but each one of these little pieces may by another blow be broken into pieces still smaller.

What is divisibility?—Every body of matter may be cut or broken into pieces. This is one of the qualities or properties of matter, and we call it *divisibility*.

Divisibility is the property of matter in virtue of which a body may be separated into parts.

Are examples of great divisibility common?—There are bodies all around us so small that we can not see them. They are in the air we breathe and in the water we drink. Some of them are alive and some are not. Many of them are so very small that we need the most powerful microscope to see them at all. Yet every one is made up of pieces or parts which are of course smaller than itself.

For example: the dust which clings to one's finger when he holds a butterfly or a moth is made up of very small particles, and yet each of these little particles of dust, which we can scarcely see with the naked eye, is found, by using the microscope, to be made up of a thousand or more little balls.

Are living creatures so very small?—And then, too, there are living creatures so small, that it may need as many as a million of them to make a pile as large as a mustard-seed. Hosts of them are living in the air and in the water all around us. They are so very very small that it has been said that a thousand of them might swim or fly side by side through the eye of a needle.

And yet each of these little creatures must be made up of still smaller parts, or else they could not move about nor devour their food, as all of them are able to do. We can not even imagine how very small these parts must be.

What are molecules?—If we keep on dividing a body into smaller and smaller pieces, we shall at last get

to a piece so very small that it can not be divided again without changing it into some other kind of matter. These smallest pieces are called *molecules*.

Molecules are particles of matter which can not be divided without changing their nature.

Does every body occupy space?—Every little particle of dust, and even a molecule, must have some size. You can not even think of a body which should have no size at all. The very smallest body you can think of fills up a little room or space. And then every larger thing, a shot for example, or a cannon-ball; the world itself, so many millions of times larger than the ball; and the sun, which is fourteen hundred thousand times larger than the world,—each of these bodies has its own particular size, or, in other words, each one fills a certain portion of space.

To occupy space is one of the properties of all matter: it is called *extension*.

Extension is the property of matter in virtue of which a body occupies a certain portion of space.

Can wood and water fill the same place at once?—If we fill a goblet with water, and then gently push a small stick down into it, the water runs over. We see in this way that wood and water can not be put into the same place at the same time.

Can water and air fill the same place at once? Boys sometimes turn a goblet bottom upward, and then push it down into a vessel of water to see the air keep the water out of the goblet. The air will not let the water in, because they can not both be in the same place at once.

Can not a nail be driven into the same place with wood?—When a nail is driven into wood, the particles of the wood are squeezed nearer together so as to make room for the nail to enter. The wood and the nail do not fill the same space at the same time.

What is impenetrability?—No two bodies can ever be in exactly the same place at once. This is one of the properties of matter. It is called *impenetrability.*

Impenetrability is the property of matter which does not allow two bodies to occupy the same space at the same time.

Can not water and sugar be put into the same space at once?—Try an easy experiment in this way: fill a goblet to the very brim with water, so that not a drop more can be added without running over. Then take some fine sugar, and very slowly sprinkle it into the water. Quite a large quantity may be put into the goblet before a single drop of water will overflow. It would at first appear that water and sugar have been here put into the same space at the same time.

Describe the experiment with shot.—Take another goblet and fill it with shot, and then pour fine sand upon the shot. The sand will, of course, fall down between the shot, and a large quantity will be poured in before any will run over. Now the sand only fills up the *space between* the shot; no one would think of saying that the sand and shot fill the same space at once.

How does this explain the experiment with sugar and water?—Now the sugar and water act in the same way as the sand and shot. The fact is that water is made up of little balls or molecules, and the

molecules of sugar are little enough to fall into the spaces between them. The two things do not occupy the same space at once.

What should we learn from the experiment?—We see that there must be spaces between the molecules of water into which the sugar falls. It is true also of all other bodies that there are spaces between their molecules. On this account bodies are said to be *porous.*

Porosity is the property of matter in virtue of which there are spaces between its molecules.

How was gold shown to be porous?—A long time ago, at Florence, a hollow globe of gold was filled with water, shut up perfectly tight, and then put under immense pressure. The water actually oozed through the gold, and, like a gentle dew, covered the outside. The water must have come through between the molecules of the gold, so that we know that even gold is porous.

What is elasticity?—We all know that a piece of india-rubber can be pulled out to a great length, and that it will afterward spring back again. We have also doubtless seen a steel wire straighten itself quickly after being bent. The quality or property which causes these bodies to spring back is called *elasticity.*

Elasticity is the property of matter in virtue of which a body springs back after having yielded to some force.

Is glass elastic?—The balls which boys use to play "marbles" with are sometimes made of glass, and every one knows how well one of these balls will bound upward when thrown upon the floor or pavement. Now the little ball is actually flattened at the moment when it strikes the floor, but the next instant the flattened part *springs*

back, and it is this springing back which throws the ball into the air. This shows that glass is very elastic.

Are all bodies elastic?—All bodies are more or less elastic. Lead and clay have but little elasticity, but even lead is elastic, for we find that two lead balls after being struck together will bound a little.

On the other hand, glass and ivory are among the most elastic solids we know of.

What becomes of water that boils away?—When water boils, steam is formed. Now let us prove that all the water which disappears is changed into steam.

We will first notice that when a cold body is held in a cloud of steam it is soon wet, which shows that by cooling the steam we get back water from which it was made.

Now let us put just *one pound* of water into a vessel and boil it. Let the steam pass through a pipe into another vessel which is kept cold. The steam goes over into the cold vessel, and is changed back into water. When the water is all "boiled away" from the first vessel we shall find just *one pound* of water in the other All the water which disappeared was changed into steam Not a particle was destroyed.

Is this true when the steam goes into the air?—When the steam goes off into the air, as it usually does, its particles are so widely scattered that they disappear entirely, but every one of them is still in existence somewhere.

What becomes of wood when it burns?—When wood is burned, one part of it is changed into ashes, and the rest changes into smoke and vapor. Not a single particle of it is ever destroyed.

What is indestructibility?—Man may thus change

the shape and condition of bodies, but he can not destroy a single molecule of any thing. On this account matter is said to be *indestructible.*

Indestructibility is the property of matter in virtue of which it can not be destroyed.

What is compressibility?—When we squeeze a sponge in the hand we press its particles nearer and nearer together, and finally make the sponge much smaller than it was. Bodies which can be made smaller by pressure are said to be *compressible.*

Compressibility is the property of matter in virtue of which a body can be made smaller by pressure.

Is air compressible?—Air is very compressible. You may learn this from so humble a thing as a pop-gun. Before the stopper is blown out, you can see that the air behind it is crowded into perhaps not half the space it filled at first.

Is water compressible?—Water is very slightly compressible. Very great pressure is needed to compress it enough to show that it is compressible at all. A pressure which would compress air into less than a hundredth part of its natural bulk would not compress water, enough to be noticed.

Are all bodies compressible?—All bodies are more or less compressible. Air is one of the most compressible of all substances, and water is one which is among the least compressible.

Are molecules compressible?—All that pressure can do to a body is to push its molecules nearer together: we do not suppose that it makes the molecules themselves any smaller.

When air is compressed into a hundredth part of its

natural volume, its molecules have been pushed a hundred times nearer together than they were at first.

What is density?—Now when the air is so much compressed there is much more of it in a given space, a cubic inch for example, than there was before. In this condition it would be said to be more *dense.*

Density has reference to the quantity of matter in a given bulk.

What is inertia?—Masses of matter have no power to move themselves nor to stop themselves when once in motion. The clouds move along in the sky, not because they choose to do so, but because they are pushed along by the wind. An apple falls from the tree, because it is pulled down by an influence, soon to be described, called gravitation; and rocks rest in their places, not because they have any power in themselves to do so, but because they are held there by forces acting upon them. Bodies of matter have no power to change their own condition, and on this account they are said to be inert. *Inertia is the property of matter which does not allow a body to change its own condition of rest or motion.*

Are molecules ever at rest?—Masses of matter are often at rest; it is believed that molecules never are. On the contrary, it is thought that the molecules of every body are forever in motion.

You have perhaps seen a cluster of bees at the door of their hive, or of ants at the entrance to their nest, all huddled together and hurrying over and around each other in constant and curious motions. Now if our eyes were powerful enough to see the little molecules of which a block of wood is composed, it is thought that we should witness a

scene of activity still more curious and constant, for every molecule in all the vast number which the block contains is in rapid motion. Philosophers believe that not a single one in all the world was ever for a moment still.

In what respect are the properties so far described, alike?—If we think again of the properties which we have just examined, we find that they are all of such a character that *a body may show that it has them without any change taking place in its nature.*

A smart blow with a hammer shatters a stone into fragments, and the experiment teaches us that the stone has the property of divisibility. But every piece will still be a piece of stone, and of just the same kind as before the blow; and so we find that a body may show the property of divisibility without any change in its nature.

What are physical properties?—All such properties,—that is, all properties which a body may show without any change in its nature,—are called physical properties.

What are chemical properties?—But all properties are not like these. Explosibility, for example, is one which a body can not show without a change in its nature.

Suppose a little gunpowder lies upon the table. You do not know whether it is explosive or not: it may be damp, and hence not explosive. But you touch it with a lighted match—a bright flash and a sudden puff occurs, and you say that the powder is explosive. Now all that is left upon the table at the spot is a dark stain. The powder itself has been changed into gases which have passed off and hidden in the air. No body of matter can show that it has the property of explosibility without changing to something else, and for this reason explosibil-

ity is called a chemical property. Chemical properties are those which a body can not show without a change in its nature.

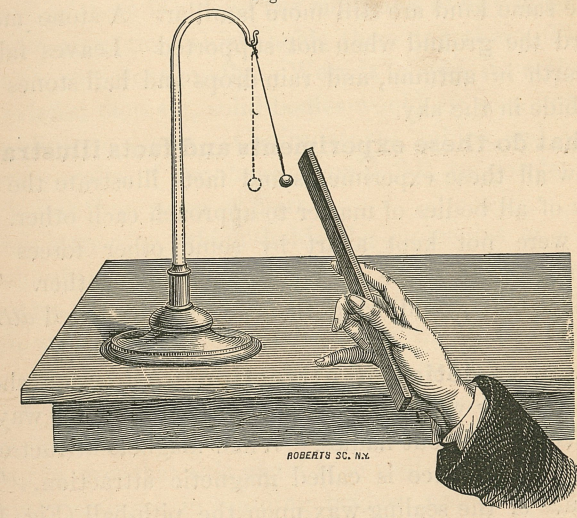
What is natural philosophy?—Natural philosophy is the science which treats of the physical properties of matter and explains those things which occur without any change in the nature of bodies.

The chemical properties of matter are to be described in the science of chemistry: we need give no further attention to them now.

ATTRACTION.

What is the effect of rubbing sealing-wax with flannel?—If we briskly rub a stick of sealing-wax with a piece of flannel or silk, we seem to give it a power which it did not have before, for if we hold it near to small bits

Fig. 1.



of cotton we see them fly quickly toward it, or if we present it to a pith-ball hung by a silk thread, the ball will be drawn aside or lifted by it. (Fig. 1.)

What may be seen on the surface of quiet water?—If we observe the surface of quiet pools of water, we

This attraction between solid and liquid bodies is very generally called capillary attraction, but it is really nothing different from adhesion.

Give examples of the action of gravitation.—A stone dropped from the hand falls swiftly to the ground, because there is an attraction between the earth and the stone. An apple bends its stem because the same kind of attraction is pulling it toward the earth, and when the fruit ripens and the stem has grown weaker, the same force causes the apple to break away and fall. This attraction is called *gravitation*. It is the attraction which acts upon all bodies and through all distances.

Give examples of pressure caused by gravitation.—Gravitation not only causes a body to fall if left without support, it also causes one body to press upon another on which it rests. A stone presses heavily upon the ground because gravitation is pulling it downward. All things upon the earth are held there, and exert their pressure, because gravitation is acting upon them. Some are held with much more force than others, as we may easily learn by trying to lift them. A pail of water hangs heavily upon the arm because gravitation is pulling it down.

What is weight?—It is easier to lift a block of wood than a stone of the same size, because gravitation is pulling the stone down with more power. To say that the stone is heavier than the wood means just the same as to say that the attraction of the earth upon the stone is stronger than upon the wood. Indeed, the *weight* of a body is only the measure of the attraction which the earth exerts upon it.

How do we tell whether two bodies have equal weights?—A pair of scales enable us to tell whether bodies have equal weights. If we put one body in each scale-pan and the two are balanced, we know that gravitation is pulling one down just as much as the other; in other words, the two bodies are equal in weight.

What are sets of weights?—A piece of metal upon which the earth exerts a certain amount of attraction may be called an ounce *weight;* then another upon which the attraction is twice as great is called a two-ounce weight; and if upon a third the attraction is sixteen times as great as upon the first, it would be a sixteen-ounce weight, or a pound avoirdupois. Several such pieces of metal, made with care to represent the various units of weight, form what is called a "set of weights," to be used in weighing the various articles in trade.

In what direction does the earth attract bodies?—The earth attracts all bodies toward its center. From whatever point a ball is dropped, it will fall in a straight line toward the center of the earth.

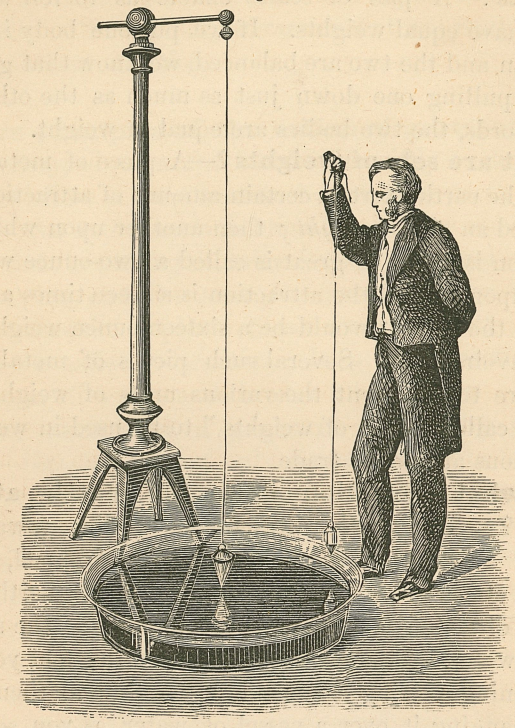
This direction is always perpendicular to the surface of still water. You can easily examine this fact yourself by fastening a string to some heavy body and then holding or hanging it over a vessel of water, as you see it in the picture. (Fig. 3, p. 26.) The string shows the direction of the force of gravity * exactly, and it is easy to see that it is perpendicular to the surface of the water.

Such a cord and ball is called a *plumb-line:* builders use it to find out whether their walls are vertical.

Does gravity always cause motion downward?—While the earth's attraction is forever downward, yet it does sometimes produce motion upward. For ex-

* The earth's attraction is sometimes called gravity.

Fig. 3.



ample, it lifts the higher scale-pan of a balance by pulling the other downward at the same time, with greater force.

In the same way gravitation causes the upward motion of smoke by pulling the heavier air down under it, thus pushing it upward.

Why does a cork rise in water?—One more illustration will be enough. A cork at the bottom of a vessel of water quickly rises to the surface. Now it does not rise because it is light, as many people will say it does. The

fact is that gravitation pulls both the cork and the water downward, but it pulls the water with the greatest force. The water must go down under the cork, and in doing so must push the cork upward.

Is the earth attracted by small bodies?—To say that the earth attracts an apple is not more true than to say that the apple attracts the earth. The truth is simply that they attract each other. The earth attracts every body great and small, and every one attracts the earth in return. Every leaf and every rain-drop or snow-flake that falls to the ground attracts the earth just as truly as it is attracted by it.

Is the earth moved by this attraction?—The earth attracting the rain-drop, makes it fall toward the ground; the rain-drop attracts the earth in return: can we suppose that the great earth moves up to meet it? We have seen thousands of rain-drops fall, but who ever saw the earth go up to meet them! And yet perhaps it does, for we could not see it if it did. The attraction would make the drops go as many times farther than it would the earth, as the earth is times heavier than the drops, and it would not be possible to see the motion through so small a distance.

Is gravitation confined to the earth?—But this force is not confined to the earth and the bodies near its surface: the sun and all the other bodies in the heavens attract each other. It is exerted by every body of matter upon every other in the universe. Grains of sand are held by it in their places on the sea-shore, and it keeps the sea itself from rising out of its bed. It is at the same time acting upon the earth itself and upon all the other heavenly bodies to keep them in their orbits.

On what does the strength of this force de-

pend?—The strength of gravitation depends upon two things: first, upon the quantity of matter in the body exerting it; and second, upon the distance through which it acts.

If the quantity of matter is doubled the attraction will be doubled also. Or, in general terms, *the attraction is in proportion to the quantity of matter exerting it.*

But if the distance be doubled the attraction will be only one fourth as strong. At three times the distance the force is only one ninth as strong. In general terms we say, *the attraction is inversely as the square of the distance between the bodies.*

What is the center of gravity of a body?—Boys are sometimes very fond of balancing books or ball-clubs, or even long poles, upon the end of a finger. They often become very skillful in doing this, without knowing that every time they do it they are trying an experiment in natural philosophy. The fact which the experiment illustrates is this: there is *a point in every body which if supported the whole body will be at rest.* This point is called the center of gravity. The ball-club has a center of gravity, and if the finger can be kept exactly under that point the club will not fall.

Illustrate by using a ruler.—Or, to study this subject further, let a ruler be balanced across your finger. There will be just as much of the weight of the ruler on one side of the finger as on the other, and a point exactly over the finger and in the middle of the ruler is the center of the weight of the ruler, or, as we have already named it, the center of gravity.

Every body has a center of gravity, and when this point is supported the whole body will be at rest.

Where is the center of gravity of a body?—The

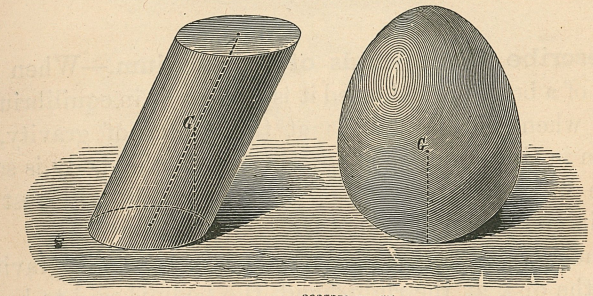
How many cu. centimeter in a cu. inch?

center of gravity is not always in the center of the body. Suppose one end of your ruler to be loaded with lead: you would then have to put your finger nearer to the heavier end in order to balance it; the center of gravity would be nearer to the loaded end.

When two boys are playing at seesaw the support of the board must be under the center of gravity, but if the boys are not of the same weight the support, as every one knows, must be nearer to the heavier boy. The center of gravity of the board and boys together is nearer to the end where the large boy sits.

In Fig. 4 the center of gravity in each body is at G.

Fig. 4.

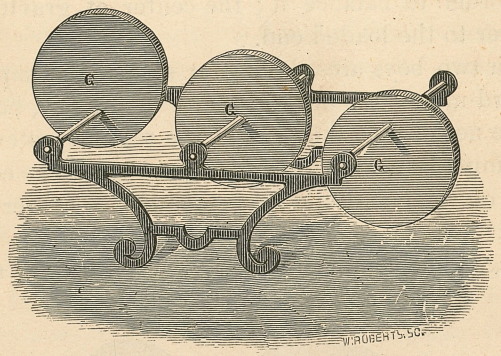


What is the line of direction?—Now imagine a vertical line drawn through the center of gravity, as shown by the vertical dotted lines in Fig. 4. This line will show the direction in which the body would fall if it were left without support, and it is called the *line of direction.*

Where may we place the support for the center of gravity?—We may support the center of gravity by placing the support at any point in the line of direction. It may be placed *at* the center of gravity, or at some

point *above* it, or at some point *below* it. Fig. 5 shows a disk of metal supported in these three ways.

Fig. 5.



Describe three kinds of equilibrium.—When all parts of a body are balanced it is said to be in equilibrium. Now when the support is at the center of gravity, as shown in the middle disk of the figure, the body is said to be in *indifferent equilibrium*, because it will rest as well in one position as another.

When the support is placed above the center of gravity, as in the disk at the right hand, the body is said to be in *stable equilibrium*, because it will not rest as well in any other position.

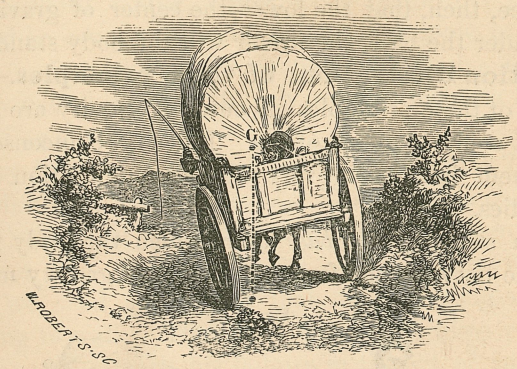
When the support is placed exactly below the center of gravity, as in the disk at the left hand, the body is said to be in *unstable equilibrium*, because the slightest force will push it over.

That a body may stand, where must the line of direction pass?—If the line of direction passes through any point in the base on which the body is placed, the body will stand, but if this line passes outside of the base,

the body must fall. The leaning cylinder in Fig. 4 does not fall, because the line of direction passes through the base, and hence the center of gravity is supported; but if it should lean a little more this line would pass outside the base, and the cylinder would tip over. A table stands very firm because it is not easy to tip it so far that the line of direction would pass outside the base.

Carriages may lean considerably to one side without overturning (Fig. 6), but an accident is sure to happen if

Fig. 6.



they lean so far as to throw the line of direction beyond the lower side of the wheel.

Upon what does the stability of a body depend?—Now some bodies stand more firmly than others, and in looking for the reason we find that the stability of a body depends upon two things. The first of these is the height of the center of gravity above the base.

A wagon loaded with hay overturns easily, while if loaded with stone it would pass the same spot in the road with perfect safety. The center of gravity of the load of hay is so much higher, that to lean a little throws the line

of direction beyond the wheel. The higher the center of gravity of any body is, the more unstable will it be.

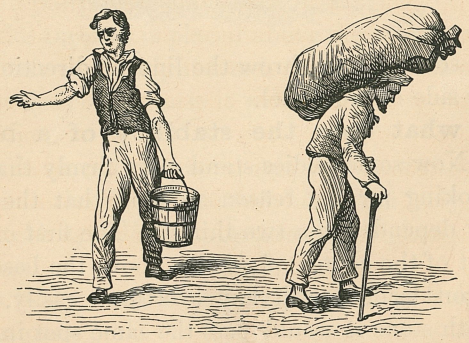
What else influences the stability of a body?—The size of the base is the second thing that influences the stability of a body. It will of course be more difficult to tip the line of direction beyond a large base than beyond a small one. A narrow boat overturns more easily than a wide one, or, to mention an example which you may see at any time, a thick book will stand upon its end more firmly than a thin one of the same height.

We see, then, that the lower the center of gravity and the broader the base, the firmer will the body stand.

Mention illustrations of these principles.—Illustrations of these principles of center of gravity are among the most common affairs of life. Indeed, we unconsciously apply them in almost every motion and position of our own bodies.

When standing, the *base* upon which the body rests is the space between the feet; the center of gravity must be

Fig. 7.



kept over this base or the person will fall. In carrying a pail of water we unconsciously lean to the other side, and

if the load is very heavy we at the same time stretch out the opposite arm (Fig. 7). The pack-peddler leans forward, for if he did not the heavy load would throw the center of gravity behind his feet and he would tumble backward.

What illustration does the showman furnish?—The showman offers a gold coin to the boy who will stand with his heels pressed against the wall of a room and then pick it from the floor in front of him without falling. He is perfectly safe in making the offer. For no one can stoop without falling, unless when he throws his head forward he can, at the same time, throw some other part of his body backward far enough to keep his center of gravity over his feet. He can not do this with his heels pressed against a wall.

Why is a child so long learning to walk?—When we think how narrow the base is on which a child must stand, being just the space on the floor between its little feet, and then how high is the center of gravity of his body, we need not wonder that he is so long a time in learning to walk. The many falls and bruises which the little one gets mark his failures in the art of supporting the center of gravity always over the base.

How may we try the experiment?—Let one who has forgotten how hard it was for him to learn to walk refresh his memory by trying to walk on stilts. Skill in this, like that of the child in walking, needs only the power to keep the center of gravity of the body, every moment, over some point in the base.

LIQUIDS.

How do liquids differ from solids?—The molecules of every solid substance are held together so that the body will keep whatever form you may choose to give it; but in water the molecules are held together with such feeble force that they can move among themselves with the greatest ease, and you can not give it any shape but that of the vessel which holds it.

Water and other substances, in which cohesion is so slight that the molecules move freely among themselves, are called liquids.

Is there any cohesion in liquids?—Still the cohesion in a liquid is strong enough to be detected. Look again at Fig. 2, and notice that the water would not be lifted under the disk, as it is there shown to be, unless the particles of water cling to each other. This shows cohesion among them. The drop of dew collected upon a leaf (Fig. 8) shows cohesion in water, for what else could hold the parts of the drop together?

Fig. 8.

How can we judge of its strength?—To get a better idea of the force of cohesion in water, we may watch it dripping from some support. A drop grows larger while clinging to its support, until at last it breaks away. The *weight of the drop* just at the moment when it breaks away is just enough to pull the molecules of water apart, and *measures the cohesion* in the liquid. The liquid in which there is the greatest cohesion will give the largest drops.

Is water compressible?—A famous experiment was made at Florence about a hundred years ago to find out whether water could be compressed. A hollow globe of gold was filled with water, and then the opening sealed so very tight that no water could pass it. An enormous pressure was then put upon the globe, when, to the surprise of all, the water oozed through the pores of the metal. This experiment seemed to prove that water was not compressible. But more careful experiments have since shown that water is compressible. It is in so slight a degree that the Florentine experiment was too rude to show it at all. It needs a pressure of 15 lbs. upon every square inch of the surface of the vessel in which the water is held to compress the fluid .0000503 of its bulk.

Is water elastic?—The instant that the pressure is removed from the compressed water it springs back to its former bulk, and this proves it to be elastic.

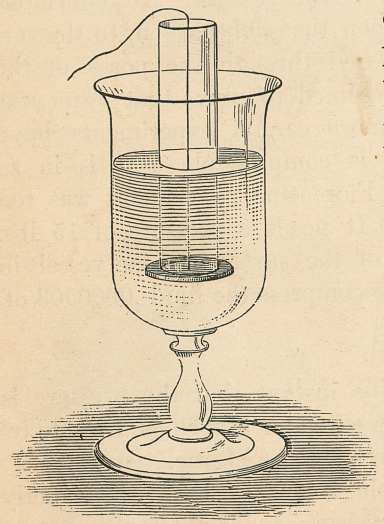
What is more remarkable, it springs back with exactly as much force as was exerted to compress it. When compressed only .0000503 of its bulk it will spring back with a force of 15 lbs. to a square inch. Now when a body springing back restores all the force that compressed it,

it is said to be perfectly elastic. Water and other liquids are perfectly elastic.

What shows the downward pressure of water?—The downward pressure of water is shown by its weight. To lift a pailful of water you must overcome its downward pressure. This may tax your strength severely, because, if the pail holds one cubic foot of the liquid, you must lift a weight of 62½ lbs; a cubic foot of water weighs 62½ lbs. or 1000 Oz. or 28.349 Kg.

Does water exert pressure upward?—To learn whether water presses upward as well as downward the following experiment (Fig. 9) may be tried. A plate of metal is hung from the end of a string, which is passed through a glass tube open at both ends. By means of this string the plate of metal may be held tightly against the lower end of the tube. Now if this end of the tube is pushed down into a vessel of water, the string may be dropped and the plate of metal will still stay up against the glass. By a moment's thought you see that it must be the water that holds the heavy metal up, and that to do this it must exert an upward pressure.

Fig. 9.

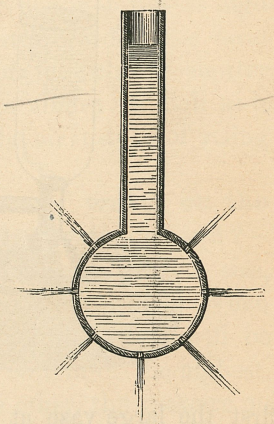


Does water exert pressure sidewise?—The same experiment shows that water exerts a pressure sidewise, for you may find that the water is gradually pushed sidewise between the plate and the end of the tube, slowly filling the tube with water.

In what direction does water exert pressure?—In fact, water and other liquids, when at rest, exert pressure in all directions. And another fact should be remembered; it is, that the pressure at any point is *equal* in all directions. If, for example, there is at any point a downward pressure of 10 lbs. there will be, at the same time, a pressure of 10 lbs. upward and sidewise, and indeed in every possible direction.

The pressure of water in several directions at once is very well shown in Fig. 10.

Fig. 10.



Why is the surface of water at rest always level?—It is because water presses equally in all directions that a body of water can not be quiet unless its upper surface is level.

Let us explain this more fully. The molecules of water move so easily that if the pressure in one direction is never so little more than in another, the liquid will move. Now if the downward pressures at all points are equal, all the other pressures must be equal too, and the water will not move, but the downward pressures will not be equal at all points unless the surface of the water is level, and for this reason the water can not rest unless its surface is level.

The wind may cover the surface of the sea with ripples

will be the same in all. Suppose, for example, that each vessel has a bottom whose surface is ten square inches; one of them may be just as large at the top as at the bottom, another may be larger at the top, and another smaller; but when they are filled to the same height with water the pressure upon the bottoms will be alike in all.

The pressure upon a bottom of given size depends *entirely* upon the height of the water above it.

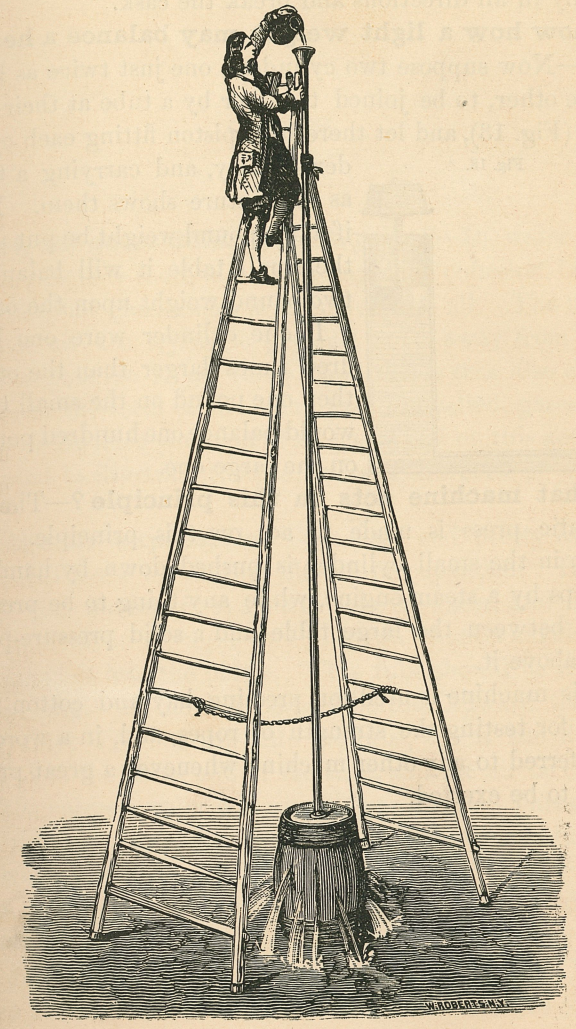
How may a little water exert very great pressure?—We may now notice a curious fact, which seems at first to be impossible. *A very small quantity of water may exert an enormous pressure.*

Fig. 12 shows how this may be proved. In the first place, a very tight cask is filled with water and a tall tube is afterward screwed into the top. By filling this tube with water the cask, unless uncommonly strong, will be broken asunder. The very small quantity of water in the tube, no more than a child could lift, exerts a pressure strong enough to break the staves of the cask.

How can this be explained?—Suppose the end of the tube is $\frac{1}{50}$ of a square inch, and that the tube is high enough to hold a pound of water. The pressure on $\frac{1}{50}$ of an inch would be one pound, and on a whole inch it would be 50 lbs. And since water presses equally in all directions there would be 50 lbs. pressure on *every* square inch of the inside surface of the cask. Such a pressure is more than the cask can bear.

Would any other equal pressure have the same effect?—Any other pressure equal to the weight of the column of water in the tube would have the same effect. The pressure of your hand, or of a pound-weight of metal, might take the place of the pound of water in the tube;

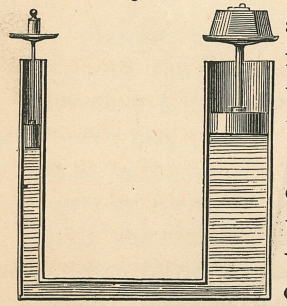
Fig. 12.



the pressure, exerted in any way, would be transmitted equally in all directions and break the cask.

Show how a light weight may balance a heavy one.—Now suppose two cylinders, one just twice as large as the other, to be joined together by a tube at their bottoms (Fig. 13), and let there be a piston fitting each cylinder exactly, and carrying a table as the picture shows them. Now if a one-pound weight be put upon the small table it will balance a two-pound weight upon the other.

Fig. 13.



If one cylinder were one hundred times larger than the other, then one pound on the small table would balance one hundred pounds on the large one.

What machine acts on this principle?—The hydrostatic press is made to act on this principle. The piston in the small cylinder is pushed down by hand, or perhaps by a steam-engine, while any thing to be pressed is put between the large table and a solid pressure-plate built above it.

This machine is used for pressing hay and cotton into bales, for testing the strength of ropes, and, in a word, it is preferred to any other machine whenever a great pressure is to be exerted.

GASES.

How do gases differ from liquids?—In water and in other liquids there is a slight degree of cohesion, but in air and other gases there is no cohesion at all. The molecules of air are trying to get just as far away from each other as possible at all times; and this is true also of all bodies in the form of air, or, as they are called, gases.

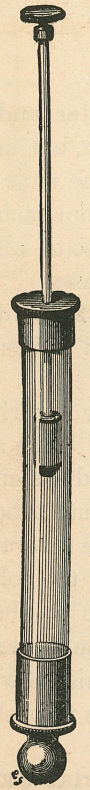
Air is the most common of all gases, and on this account it is used to illustrate the properties of this class of bodies.

Is the air expansible?—An easy and pretty experiment will teach us whether air can be expanded. Take a small vial having in it a little colored water, and fasten into its neck an air-tight cork, through which a small tube just reaches into the bottle. This tube should be several inches long. If the vial be held bottom upward the colored water will not run into the tube, but if the lips be applied to the lower end of the tube, and the air be drawn out, the colored water will quickly run down. This shows that the air above the water in the vial expands to push the water out.

In what other way is the air of the vial expanded?—If, instead of taking the air out of the tube, you gently warm the vial, you will see the colored liquid move out of the vial and down the tube. In this experiment the air is expanded by heat.

Boys sometimes amuse themselves by bursting balloons or bladders filled with air by warming them. They thus illustrate the expansibility of air, for the air when heated tries to fill more room than it did when cold, and in trying to get larger bursts the balloon with a loud report like a gun.

Fig. 14.



Is air compressible?—If we take a cylinder with a piston fitting it air-tight (Fig. 14), we may easily push the piston down some distance into the cylinder. No air gets out, but the piston, while going down, crowds the air along before it until the cylinder may be less than half full. By greater force than can be given by the hand alone the piston may be crowded down until the cylinder may be less than a hundredth or a thousandth part full.

Is air elastic?—Compressed air will spring back to its original bulk when the pressure is taken away, and this shows that it is *elastic*.

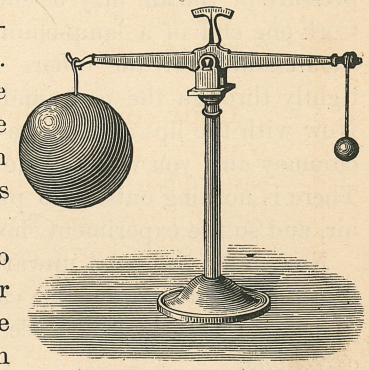
It is also found that air after being compressed will spring back with just as much force as was put upon it; this shows it to be *perfectly* elastic.

Does air have weight?—A thin globe made of glass or metal is weighed when full of air (Fig. 15). The air is then taken out of it by means of an air-pump, soon to be described, and the empty globe is weighed. The globe weighs more when full of air than when empty, and this proves that air has weight.

If the globe will hold 100 cubic inches of air, it will weigh about 31 grains less when empty, and this shows that 100 cubic inches weigh about 31 grains.

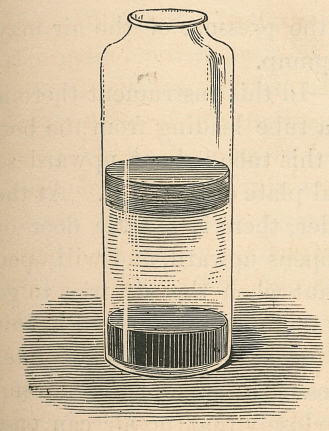
Does gravitation act upon air?—The weight of air, like the weight of wood or iron, is caused by the attraction of gravitation. Gravitation acts upon the invisible air in just the same way that it does upon water or upon oil, only its action is not so strong.

Fig. 15.



Try this experiment: into a tall glass jar (Fig. 16) or even a goblet put first some water, and then pour in some oil; the oil will lie on top of the water. Afterward, if you can have some mercury you will be able to pour it into the jar carefully without disturbing the other liquids. The mercury will go to the bottom and form a layer under the others.

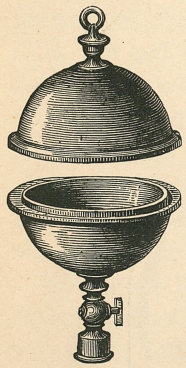
Fig. 16.



Now there are *four* substances in the jar, arranged in layers. There is first mercury, then water, then oil, and then *air*. And they are in this order because gravitation is strongest on mercury, weaker on water, weaker yet on oil, and weakest on air. For a similar reason the water of the sea is above the rocks and then the atmosphere above the water; but if grav-

How may the pressure be shown by the Magdeburg cups?—Fig. 18 shows the Magdeburg cups. These cups are made of metal, and their edges are so smooth that they will fit each other air-tight. The lower one may be screwed upon the pump-plate, the other then placed upon it and the air taken out. They may then be removed from the pump without letting the air get into them, and when this is done, the pressure of the outside air will hold them together with great force. The illustrious Otto de Guericke of Magdeburg, who invented the air-pump, and to whom we also owe the invention of these cups, made a pair so large that it needed the strength of four horses to pull them apart.

Fig. 18.

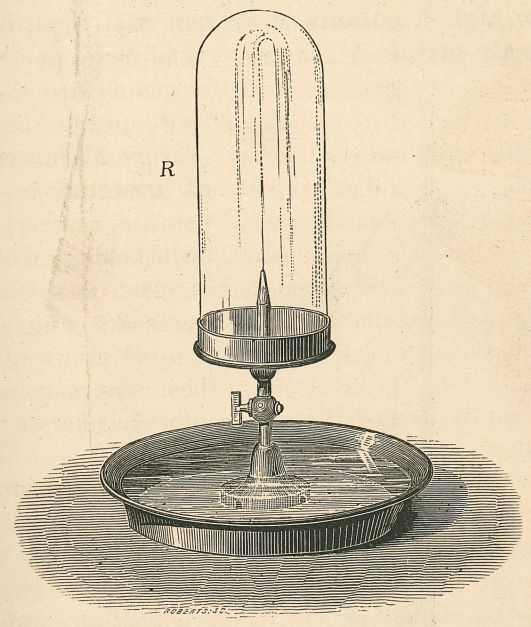


How may the pressure be shown by the fountain in vacuo?—The pressure of air is shown by a still more beautiful experiment, represented in Fig. 19. A tall glass receiver, R, made air-tight, has a tube passing through the bottom. The lower end of this tube may be screwed upon the plate of the air-pump: the other end reaches some distance into the vessel. After the air is exhausted from the receivers, if the lower end of the tube is placed in water and the valve opened, an elegant fountain will be thrown up inside by the pressure of the air upon the water outside.

How may the upward pressure of air be shown?—We do not need an air-pump to show the upward pressure of air. Just take a common bottle and fill it to the brim with water; then place a piece of paper over its mouth, and while you hold the paper with one hand, turn

the bottle bottom upward with the other. You may now let go of the paper and the water will not run out of the

Fig. 19.



bottle. The water and the paper are both held up by the upward pressure of the air. If the neck of the bottle is very small, the paper need not be used.

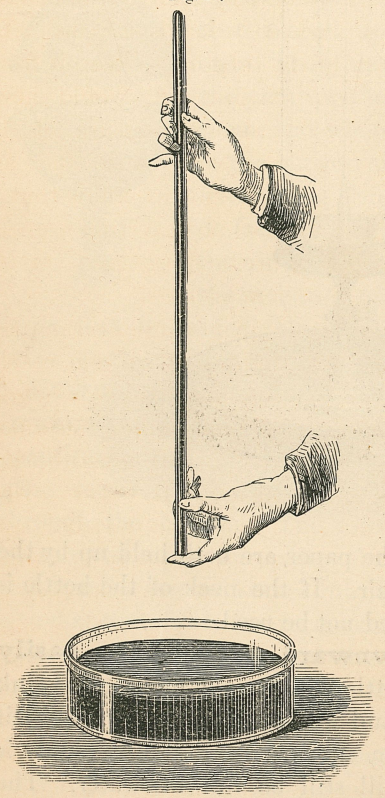
How may the downward pressure be easily shown?—Take a tall bottle with a wide mouth, and sink it in a vessel of water, and when full of the liquid lift it gradually with its bottom upward until its neck only is covered. The bottle will still be full of water. The pressure of the air on the water in the vessel pushes the liquid up into the bottle and holds it there.

It is the pressure of air which also drives water through

a glass tube or a straw when, one end being in the liquid, the lips are applied to the other end. All that the lips do is to take the air out of the tube above the water.

How high a column of water will the pressure of the air sustain?—The water will be sustained to a height of about 34 feet by this pressure of the air.

Fig. 20.



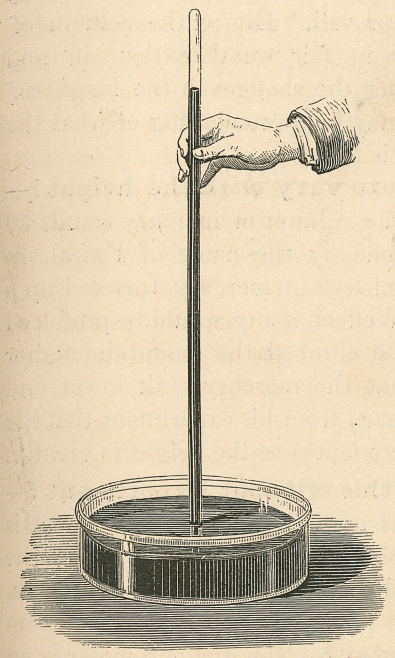
How high a column of mercury?—A column of mercury about 30 inches high will weigh as much as a column of water 34 feet high if they are of the same size. Therefore, a column of mercury only 30 inches high will be supported by the pressure of the air.

Can we prove this by experiment?—The pictures show how this can be easily proved by experiment. A glass tube more than 30 inches long is taken. One end of it is closed, the other open. It is first filled with mercury, and then the open end is shut with the finger, while the tube is turned, closed end upward, as shown in Fig. 20. The open end is then put into a dish of mercury and the finger taken away. The mercury will no

longer quite fill the tube, but will sink so as to leave the upper part empty, as shown in Fig. 21. The air-pressure supports this column of mercury, and the height measures about 30 inches.

How much pressure does the atmosphere exert upon a square inch?—A column of mercury one inch square and thirty inches high will weigh 15 lbs. To balance 15 lbs. of mercury in the tube, or to keep it from falling out, would need another pressure of 15 lbs., and since the air does this we know that it must be exerting a pressure of 15 *pounds to the square inch.*

Fig. 21.



Air is lighter than the lightest down, but reaching above us to a height of many miles, the quantity in all must be immense. It covers every thing upon the earth, and presses upon each square inch of the surface of every thing with a force of 15 lbs. The total pressure upon each one of our bodies is said to be about 20,000 lbs. We are able to bear this great pressure without feeling it, because it is so exactly equal in all directions, and because every point on the body, bearing its own share, divides the labor so justly that no point is burdened.

Is the pressure of the atmosphere always alike?—By watching the column of mercury in the tube, Fig. 21, it will be found to be higher at some times than at others. This must be because the pressure of the atmosphere is not always the same. It is sometimes a little more than 15 lbs. to the inch and sometimes a little less.

How does the pressure vary with the weather?—In bright, clear weather the atmosphere is heavier than when storms or clouds prevail. Hence the column of mercury will be higher in fair weather than in foul weather; and by watching the changes in the height of the mercury column we may judge something of what the character of the weather is to be.

How does the pressure vary with the height?—At the level of the sea the column of mercury stands 30 inches high. A gentleman by the name of Pascal, in France, with a tube and cistern of mercury, traveled up a mountain-side to find what effect, if any, would be produced upon the column. As he climbed the mountain higher and higher, he found that the mercury sank lower and lower in the tube. We learn from his experiment that the pressure of the atmosphere is less as the height is greater.

May we not know this without experiment?—Indeed, no experiment is needed to prove this, for it is very clear that when going up we leave a part of the atmosphere below us, and there being then less above us, the pressure exerted must be less.

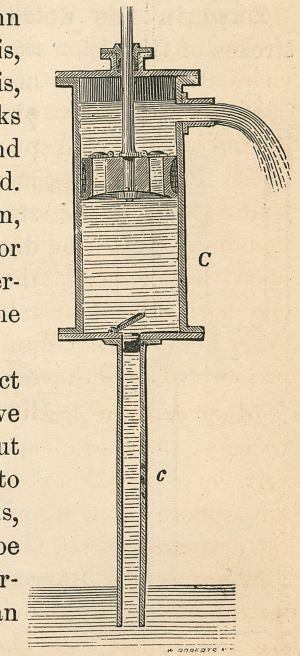
What is the Barometer?—Now the barometer is an instrument which shows the changes in the pressure of the atmosphere. It consists of a tube with a cistern of mercury, like that shown in Fig. 21, placed in a framework of wood or metal which protects it from injury. A

scale placed behind the tube shows the height of the mercury column.

How does this instrument foretell changes in the weather?—By the *motion* of the mercury up or down we may judge something of the future character of the weather. If we see the mercury rising, we may expect fair weather: if the mercury falls, we may expect foul weather.

How is it used to find the height of mountains?—From the sea-level to the top of Mont Blanc is a height of about 15,000 feet. In going to the summit, the mercury column falls about 15 inches. From this, and other observations like this, it appears that the mercury sinks about one inch for every thousand feet the barometer is taken upward. To get the height of a mountain, then, we may count 1,000 feet for every inch through which the mercury falls in being carried to the summit.

Fig. 22.



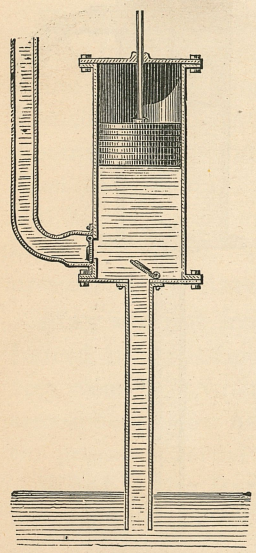
This rule will not give the exact height, owing to things which we will not now try to explain, but when all things are taken into account in making the calculations, the height of a mountain may be calculated by the barometer perhaps more easily and exactly than by any other method.

Describe the lifting-pump.—In this very common and useful instrument the pressure of the atmosphere is

ade to lift water from a well or cistern. Its parts and their action are very well shown in Fig. 22. It consists of two cylinders, one above the other, the upper one, *C*, being often much larger than the other, *c*, which reaches down into the well. Where these cylinders join each other there is a little door, or valve, which opens upward, and will allow water to go up, but will not let it go down again. In the upper cylinder there is a piston which may be lifted or pushed down by the handle of the pump. In this piston there is a valve, or, it may be, more than one, which opens upward.

Explain the action of the pump.—By the first strokes of the piston the air is taken out of the cylinders, and then the pressure of the atmosphere upon the water in the well pushes the water up into the pump just as it will push water up into a straw or other tube when the air is drawn out at the top by applying the lips. After the air has been all taken out, the water will fill the pump full to the spout, and then every time the piston is raised it will lift a portion of water out at the spout, while more is pushed in at the bottom by the air to take its place.

Fig. 23.



Describe the force-pump.—Fig. 23 shows a kind of pump which is used for throwing water to greater heights. It is called the *force-pump*. The spout is at the bottom of the upper cylinder instead of near the top of it, as in the lifting-pump, and instead of having any valve in the piston

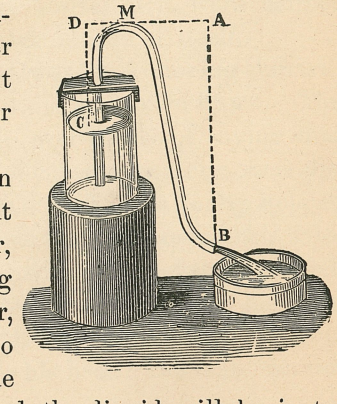
there is one opening into the spout. In other respects it is like the lifting-pump.

Explain its action.—When the piston is lifted the atmosphere pushes water up into the upper cylinder. When the piston is pushed down the water is pushed through the valve into the spout. This spout may reach even to the top of a house, and the water will go higher by each stroke of the piston until it reaches the top and runs over. A *jet* of water would be thrown out by each downward stroke of the piston, but if a *steady stream* is wanted, the spout leads into an air-chamber where the water condenses the air. This condensed air exerts a steady pressure on the water in the chamber and throws it out in a steady stream.

The fire-engine is a form of force-pump. In the steam fire-engine the piston is moved by the power of steam.

What is the siphon?—In Fig. 24, the tube from which the water appears to be running is a siphon. The instrument is used to pass a liquid from one vessel to another. The siphon is never any thing more than a bent tube, one arm being longer than the other.

Fig. 24.



How is it used?—When the siphon is to be used, it must first be filled with water, and then the end of the long arm is closed with the finger, while the short arm is put into the liquid in the vessel. The moment the finger is removed, the liquid will begin to flow up the short arm, over the bend and out at the end

of the long arm; nor will it stop running until the end of the short arm is uncovered, or until the liquid is as high in the second vessel as in the one from which it runs.

Explain its action.—It often at first seems a mystery why the liquid should run upward through the short arm and out from the other; but we shall see that the forces that push it in that direction are stronger than those that push the other way.

To push it out through the long arm there is, *first*, the weight of the liquid in that arm, and, *second*, the pressure of the air on the water in the vessel.

To keep it in, there is, *first*, the weight of the water in the short arm, and, *second*, the pressure of the air upward against the water at the end of the long arm.

Now the first two forces are stronger than the last two, because the weight of the water in the long arm is greater than of that in the short arm; and the water runs in the direction of the greater force.

Reached here Oct. 5th, 1891.
G. J. Bast.
" " " 13th, 1891

Emile [illegible]

MOTION.

Can bodies move themselves?—Animals can move from place to place, because they have the power of will, and their bodies must obey it; but that a book or a block of stone should of its own accord move out of its place, we pronounce to be impossible. Such bodies of matter can move only as they are either *pushed* or *pulled*. The ship, for example, is pushed along by wind: a train of cars is pulled along by a steam-engine. A stone falls to the ground because it is pulled down by the attraction of the earth, and the smoke rises because it is pushed upward by the heavier air.

A body at rest would rest forever if it were neither pushed nor pulled by some force outside of itself.

Can bodies stop themselves?—A moving ship will not stop suddenly when the sails are taken down. The water finally stops it; no one ever thinks of saying that the ship stops itself. A train of cars moves along some distance after the steam has been cut off: it is finally stopped by the friction of the wheels as they rub upon their axles and upon the track, together with other obstacles which it meets; it does not stop itself. A horse and his rider are moving along together; let the horse suddenly stop, and his rider is plunged over his head; the man can not stop himself.

We learn from these observations that a body in motion

would move forever if it were not stopped by some force outside of itself.

Can a body change the direction of its motion?—When a ball is struck with a bat, it flies in the direction of the blow, and in no other, unless turned aside by some other force.

The same thing appears to be true of all other motions, for who ever saw a moving body suddenly of its own accord start off in another direction! A body in motion would move forever in a straight line unless turned aside by some force outside itself.

What is the first law of motion?—We may now state, in very few words, what we have thus far learned about motion, as follows:

A body at rest would rest forever, or if in motion would move forever in a straight line, unless kept from doing so by some force outside of itself.

This principle is called the first law of motion.

Why then does not a stone move in a straight line when thrown from the hand?—When a stone is thrown in a horizontal direction, we find that instead of going along in that direction, it very soon flies lower and lower, until at length it strikes the ground. It would move in a straight line if the attraction of the earth did not pull it to the ground.

Are other motions caused by more than one force?—If the wind blows while the rain falls we see the drops coming obliquely down to the ground. Gravitation alone would bring them vertically through the air, but the wind at the same time pushes them sidewise; their motion is due to these two forces.

Now, the more examples of motion we examine, the more certain we become that the motions of bodies are

generally caused by two or more forces acting upon them at the same time.

Does each force produce as much effect as if it acted alone?—Here is an experiment that any one can try for himself while studying this subject. Put a ball at one corner of a table. You may snap it with the fingers of one hand and make it roll along the side of the table, and if you afterward snap it with the fingers of the other hand you may make it roll across the end; but if you skillfully snap it with the fingers of both hands at once, it will follow neither the side nor the end, but you will see it dart obliquely across to the opposite corner.

If one hand would roll the ball the whole *length of the table* in *one second*, and if the other would roll it *across the end* in *one second*, then, when both hands are used at once, the ball will roll to the *opposite* corner in *exactly one second*. But to get to this opposite corner, the ball must go the whole length and the whole width of the table both at once; so that each force causes just as much motion in the second of time as if it were acting alone.

Give another example.—The swift motion of a cannon-ball is caused by the explosion of gunpowder, but gravitation is at the same time pulling the ball down toward the ground. If the ball is shot in a horizontal direction it will strike the ground at the same time it would if dropped from the mouth of the gun. The force of gravitation pulls the ball downward through the same distance while it is moving horizontally as it would in the same time if falling vertically.

Suppose the ball shot directly upward.—A ball will fall about 16 feet in the first second after it starts. Now suppose a ball shot directly upward, and that the force of the powder would be strong enough to send it up

100 feet in the first second: the ball will only rise 84 feet The attraction of gravitation which would make it fall 16 feet if it were not for the powder, will cut off just 16 feet from its ascent.

What is the second law of motion?—From such facts as these we infer that:

A force will cause the same amount of motion, and in the same direction, whether the body it acts upon be at rest or already in motion.

This principle is called the second law of motion.

What is meant by action and reaction?—He who strikes the table with his hand gets a blow from the table in return, as he very well knows by the pain it occasions when the blow is heavy. The hand *acts* upon the table and the table *reacts* upon the hand. Whenever two bodies act upon each other, the effect of one of them is called *action*, that of the other is called *reaction*.

A bullet may perhaps fracture a stone against which it is fired, but the bullet will be flattened, showing that the stone has returned the blow. The bullet acts upon the stone and the stone reacts upon the bullet.

Are action and reaction in the same direction?—When a book lies upon the table it presses *downward*, but the table is at the same time pressing *upward* to keep the book from going to the floor. Action and reaction must always be in opposite directions.

Which is the stronger?—Take the case of the book on the table: the action of the book downward, or its pressure, is just equal to its weight. If the table should react with a force *greater* than the weight of the book, it would throw the book upward; if with *less* force, the book would be able to break through it: it can be neither greater nor less, because the book is at rest. In

every other case as well as this, action and reaction are equal.

What is the third law of motion?—From what has just now been said we may gather this general statement:

Every action must be followed by an opposite and equal reaction.

This principle is called the third law of motion.

What is an impulsive force?—When a bullet is shot from a gun, the force of the gunpowder acts upon it only for a single moment when it starts. A force which acts for a moment only is called an *impulsive force*.

Other examples are common enough. When a ball is hit with a bat, the force of the blow is spent upon the ball in an instant. And at the moment when a stone leaves the hand that throws it, the force of the hand is spent. Both of these are impulsive forces.

What do we notice about the motion caused by impulsive forces?—We notice that the motions produced by these impulsive forces are all alike in one thing at least: the velocity is greatest at the beginning. The speed of the bullet is greatest at the moment when it leaves the gun, and grows less and less until it is stopped entirely. And in the case of the ball struck with a bat, and of the stone thrown from the hand, motion is swiftest at the beginning and gradually grows slower.

Why do these motions grow slower?—It would not be so if it were not for the resistance of the air. The resistance of the air which hinders the snow-flakes so that they can not fall like rain-drops or hail-stones, also hinders the motion of every thing else.

Cut a leaf of paper into pieces an inch in length and half as wide; toss them upward into the quiet air of the room and watch their slow and curious motions to the

floor: if it were not for the air which hinders them they would fall like bullets.

The air hinders the motion of heavy bodies, and the faster they move the more it will affect it. Even the motion of cannon-balls is rapidly lessened by the resistance of the air.

Now if there were no air nor other resistances the motion caused by an impulsive force would not grow less. The moving body would pass over equal distances in equal times, or in other words, its motion would be uniform.

What is a constant force?—The force of the hand which tosses a stone upward into the air is an impulsive force, but gravitation which brings it down again is not. Never for a single instant does gravitation cease to act upon the falling stone, and on this account it is called a *constant force*. A constant force is one whose action is all the time alike.

What do we notice about the motion it produces?—The motion of a falling body is swifter and swifter the farther it falls. This is true not only of motion caused by gravitation, but of motion caused by any constant force whatever; the velocity increases while the force is acting.

How do the air and other resistances affect this motion?—In this case also the resistance of the air hinders the motion, and it hinders it more and more as the velocity is greater. In fact, the motion of a body falling from a great height may become so swift that the resistance of the air will be as strong as the force of gravitation itself, and after that moment the motion will be uniform.

It is just so with a train of cars. The power of the steam starts it and for a little time makes it go faster and faster, but the motion soon becomes uniform because the

many resistances which the train meets soon equals the power of the steam.

The motion of a sail-boat increases at first, but very soon the resistance of the water becomes so strong that it needs the whole force of the wind to overcome it, and after that the boat sails on at a uniform rate.

In what kind of a path will an arrow go?—If an arrow is shot from the bow directly upward, it will go up in a straight line and its motion back again will also be in a straight line. If, however, the arrow be fired in any other direction its path will be a curve instead of being straight.

Why will the path of the arrow be curved?—It is easy to see that there are two forces acting on the arrow. There is, first, the force of the bow which sends it forward, and then, second, the force of gravitation which pulls it toward the ground. The bow would send it in a straight line, but gravitation is all the time pulling it down out of that line. The arrow obeys both of these forces at once, going forward and downward at the same time, its direction changing a little all the time. For this reason the path of the arrow is curved.

In any case, if a body moves in a curved path it is being acted on by two forces, and one of these, at least, must constantly act.

Give another example.—We may make an easy experiment to illustrate this statement more fully. Tie a string to the stem of an apple and make the apple swing around the hand in a circle. You can feel the apple pulling as if struggling to get away from the hand, and should you let go your hold of the string the apple would dart off in a straight line in just whatever direction it happened at the moment to be going.

What two forces make the apple move in the

circle?—There is one force, we notice, which is trying to move the apple in a straight line, and the string is another force which is pulling it out of that line every moment.

By these two forces acting together the apple is moved in a circle.

What are the forces which produce curved motion?—Now one of the two forces by which curved motion is produced is the *projectile* force, and the other has been called the *centripetal* force. The one which would send the body away in a straight line is the projectile force; that which pulls it out of the straight line is the centripetal force.

What is the centrifugal force?—The force which you feel pulling the apple away from the hand in the experiment is the *centrifugal* force. It is only the resistance which the apple in motion offers to being drawn out of a straight line. It takes no part in the production of the curved motion. The centrifugal force is the resistance of a body in motion to deflection from a straight line.

What familiar examples of the action of these forces?—The stone in a sling, at the moment when it is set at libery, darts off in a line as straight as the path of an arrow or a bullet: but before it is set at liberty, the sling-cord pulls it out of that line and keeps it moving in a circle.

A wet mop, made to turn swiftly on its handle as an axis, throws the water in all directions and soon dries itself. It is the projectile force which sends the water away. And this illustrates what we sometimes see among animals. Sheep, for example, in wet weather throw the water off themselves by shaking their fleeces in a kind of

half rotary motion. Water-dogs on coming to land dry themselves in the same way.

"A loaded stage-coach running south and turning suddenly to the east or west, strews its passengers on the south side of the road. A man on horseback when turning a corner leans much toward the corner in order to overcome the *centrifugal* force which would throw him away from it."

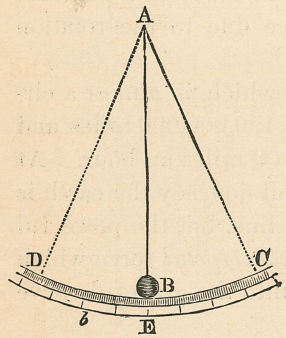
A carriage-wheel turning swiftly often throws the dirt in straight lines from its circumference. In the same way, were it not for the attraction of gravitation, all bodies on the face of the earth would be thrown out into the heavens by the *projectile* force due to the rotation of the earth upon its axis.

The earth is moving in an orbit which is almost a circle, the diameter of which is about 190,000,000 miles, and it is going at the rate of about 68,000 miles an hour. At every moment during this wonderful journey the earth is s ruggling to fly away in a straight line, but the powerful attraction of the sun is the strong *centripetal* force which constantly pulls it out of this line into the graceful curve through which it flies.

VIBRATIONS.

Describe the pendulum.—In Fig. 25 we notice a ball B hung from a fixed point A by means of a cord. This ball represents a pendulum: any body hung from a fixed point, under which it may swing from side to side, backward and forward, is a pendulum.

Fig. 25.



If such a ball were pulled aside and then dropped it would swing for a long time. You can easily try the experiment by hanging an apple in the same way and making it swing.

What is meant by vibration and amplitude?—If the pendulum (Fig. 25) is lifted to C it will swing to D, a point almost as far on the other side, and then return. It will keep on moving back and forth in this arc until the resistance of the air finally stops it at B, the place from which it first started. Its *motion* from one end of its arc to the other is called a *vibration*, and the *distance* from one end of its arc to the other is called its *amplitude*.

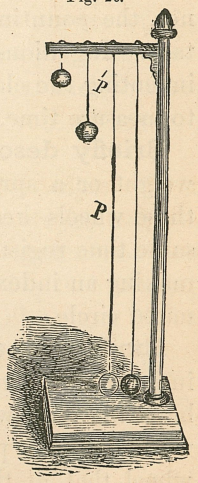
Does the time of one vibration depend upon amplitude?—The distance through which the pendulum swings makes no perceptible difference in the time it takes

to pass through it; in other words, a pendulum will swing through a long arc as quickly as through a short one. The reason that the long journey is made in the same time as the short one is this: the longer the arc the steeper are its ends, and on this account the *swifter* the pendulum will fall.

Does the time of one vibration depend upon the weight of the ball?—It is another curious property of the pendulum that whether it be made of lead or of wood or of other material, it will make its vibration in the same time. Its weight, and we may add, the material of which it is made, makes no difference in the time of one vibration.

Does the time of one vibration depend upon the size of the pendulum?—Nor does the size of the pendulum make any difference in the time of one vibration. Of course the resistance of the air will be more on a large ball than on a small one, and on that account a large pendulum will not continue to vibrate as long as a small one, but they will swing from one end of the arc to the other in the same time, while the motion does continue, no matter how much they may differ in size.

Fig. 26.



Upon what does the time of one vibration depend?—But if we take pendulums of different lengths, as shown in Fig. 26, we shall find the longest one vibrating slowest. In all cases the longest pendulum needs the longest time to make one vibration. The time of one vibration depends altogether upon the length of the pendulum.

What is the law?—If the pendulum P (Fig. 26) is just *four* times as long as another, P′, we shall find by trying the experiment that it takes just *twice* the time it does the other to make a vibration. We notice that:

The time of one vibration is in proportion to the square root of the length of the pendulum.

If then one pendulum is 9 times the length of another, it will take it 3 times as long to vibrate once.

The length of a pendulum that will vibrate in one second is about 39.1 inches: a pendulum $\frac{1}{4}$ of that length would vibrate in $\frac{1}{2}$ a second according to the law, since the square root of $\frac{1}{4}$ is $\frac{1}{2}$.

How is the pendulum used to measure time?—Now if we know the time it takes a pendulum to make one vibration, we may measure any length of time by simply counting the number made. The resistance of air would however soon stop the swinging, and, even if it did not, the counting of the vibrations would be a tedious task. Ingenious men have overcome these difficulties by inventing the clock, by which people are everywhere able to measure time.

Briefly describe its action.—In this instrument a weight or a spring keeps a set of wheels in motion, and these wheels keep the pendulum vibrating and at the same time register the number of vibrations it makes, by making an index or hand point to the divisions of a graduated circle.

Explain its action more fully.—In looking at the interior of a common clock, which is the best and perhaps the only way any one can clearly learn its action, we find that a pendulum is so connected with a toothed wheel that at the end of every two vibrations it allows one tooth to escape. If the pendulum vibrates twice a second it allows one tooth to escape at the end of each second, and if there are sixty teeth on the wheel it will turn around just once in sixty seconds or a minute. To the axis of this wheel the *second-hand* of the clock is fixed.

This wheel is connected with another that turns once around in an hour, and to the axis of this one the *minute-hand* is fastened.

There is still another wheel in the set which can turn once around in twelve hours, and to the axis of this the *hour-hand* is fastened.

How does a watch differ from a clock?—A watch differs from a clock in having a vibrating wheel, called the balance-wheel, instead of a pendulum. The vibration of the balance-wheel allows one tooth of a wheel to pass just as the pendulum does in the clock, and the number of beats is recorded in the same way.

What are chronometers?—Time-keepers of the most wonderful perfection have been made for the purpose of telling the longitude of a ship at sea, and for other purposes where great accuracy is required. They are called *chronometers.*

Concerning their perfect action Arnott says: After months spent in a passage from South America to Asia, my pocket chronometer, with others on board, announced one morning that a certain point of land was then bearing east from the ship at a distance of fifty miles; and in an hour afterwards, when a mist had cleared away, the looker-out on the mast gave the joyous call, "Land ahead," verifying the report of the chronometers almost to a mile after a voyage of thousands.

The method of using a watch to tell the longitude of a place on the earth may be found explained in astronomy.

the number of vibrations in a second is inversely as the length of the cord.

This is also true of all other cases. If one string is, for example, one tenth as long as another, it will vibrate ten times as fast.

Does the rapidity of vibration depend upon the weight of the cord?—The wire-wound string of a violin is much heavier than one which is not wound, and we find that it vibrates more slowly. The heavier the cord the slower the vibration. This is always true.

If, to be more particular, we take one cord four times as heavy as another, in all things else they being alike, it will vibrate only one half as fast. In all cases it will be true as it is in this one, that *the number of vibrations in a second is inversely as the square root of the weight of the cord.* If, for another example, we suppose one cord to weigh 16 times as much as another of the same length, it will vibrate only $\frac{1}{4}$ as fast.

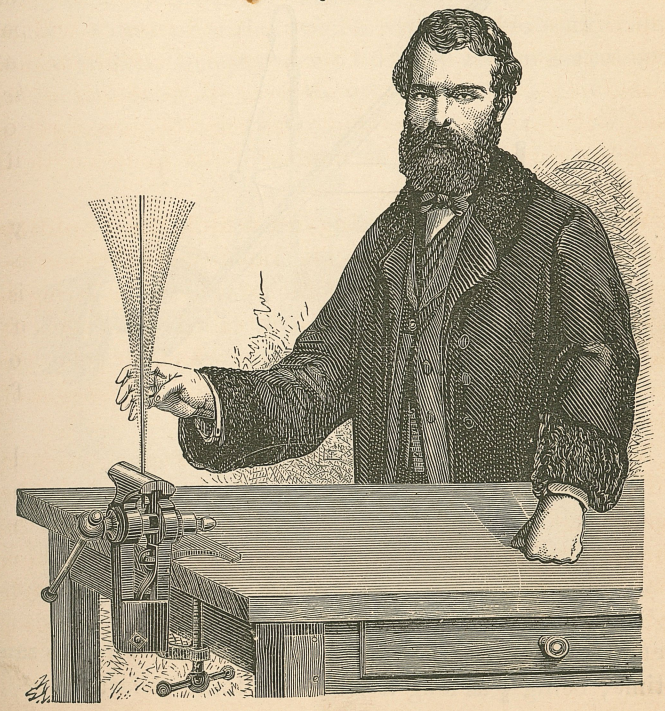
What is the third thing on which the rapidity of vibration depends?—The rapidity of vibration depends also on the weight or force by which the string is stretched. This weight or force is called the *tension* of the cord. If, for example, the weight which stretches the cord over the bridges in Fig. 27 is 56 lbs. the *tension* of the cord is said to be 56 lbs.

Now we find that, when other things are equal, the cord will vibrate faster as the tension is made greater. If the tensions of three cords are as the numbers 1, 4, 9, the number of vibrations a second will be as 1, 2, 3. But these last numbers are the square roots of the first, in their order, and this teaches us that *the number of vibrations a second is directly as the square root of the tension of the cord.*

To what are these principles applied?—In the manufacture of musical instruments in which the sounds are made by vibrating cords or wires, such as the guitar and the piano, these principles become important. The cords must each be of the right length and weight and tension, or else they will fail to give the correct tones for music.

Describe the vibration of a wire fixed at one end.—When a wire, or even a slender rod of wood, is fastened at one end in a vise, and its other end is drawn

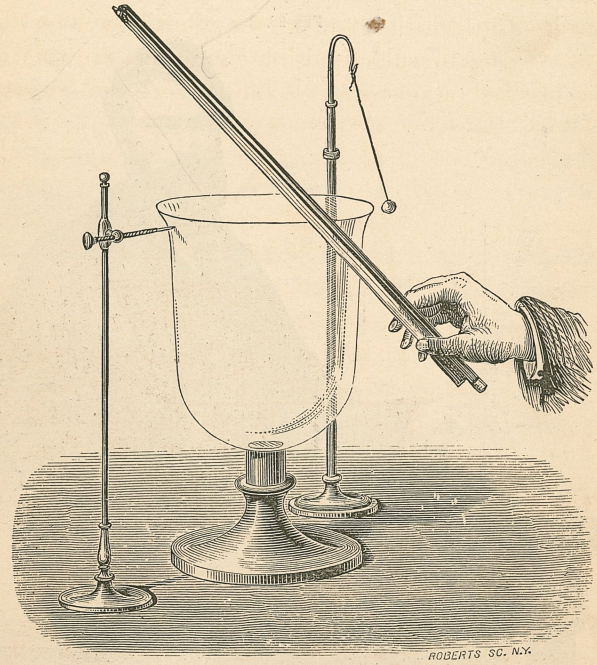
Fig. 28.



aside, it will spring back and forth so swiftly as to appear to be flattened out into a gauze-like fan (Fig. 28).

On what does the rapidity of its vibration depend?—If the rod is shortened it will vibrate faster; in a word, the number of vibrations in a second will depend on the length of the wire or rod. The law seems to be different from that which applies to cords. It states that *the number of vibrations in a second is inversely as the square of the length of the rod.* According to this law, if one rod 36 inches long makes 1 vibration a second,

Fig. 29.

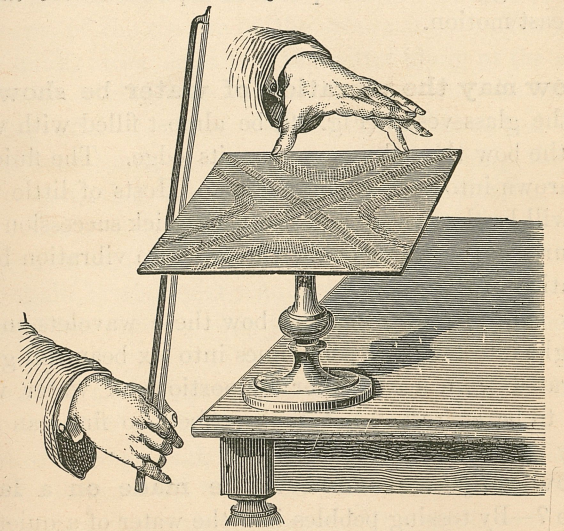


another one only 12 inches long will make 9 in the same time; being $\frac{1}{3}$ as long it vibrates 9 times as fast.

How may the vibrations of a bell be shown?—In Fig. 29 we are shown a bell-shaped glass vessel with a little pendulum-ball hanging beside it. By drawing a violin-bow across the edge of this bell we make the glass vibrate, and we shall know that the vibrations are made because the little pendulum-ball will fly back and forth with a violent clatter. The edge of the glass, springing back and forth, puts the ball in motion.

This is one of the many cases of vibration in which the motion is too delicate to be seen, and the existence of which would not be known if some way had not been discovered by which to make the vibrations show themselves. Cases of such invisible vibrations are very common. In fact, almost every solid body we can see around

Fig. 30.



us is already in, or else may be put into, a state of invisible vibration.

How may the vibrations of a brass plate be shown?—If a plate of brass is fastened at its center, and a violin-bow be drawn across its edge (Fig. 30), it will vibrate. Its vibrations may be *felt* by gently touching it with the finger, but by sprinkling fine sand all over the plate its vibrations will be shown in a curious and much more satisfactory way. The picture represents the beautiful effect which will be produced. The sand will dance about, and finally collect into straight lines and curves, sometimes in one form and sometimes in another, changing with every change in the point to which the bow is applied or upon which the finger is laid. The reason for this curious arrangement is, that some parts of the plate vibrate more than others, and the sand gathers itself upon those points where there is the least motion.

How may the vibration of water be shown?—Let the glass vessel (Fig. 29) be almost filled with water, and the bow then drawn across its edge. The fluid will be thrown into violent commotion. Hosts of little wavelets will be thrown up and down in quick succession upon its surface, the water being thrown into vibration by the vibration of the glass.

By skillfully drawing the bow these wavelets may be brought into four and sometimes into six beautiful groups separated from each other by portions of water which seem to be at rest. Not many effects so fine can be so easily produced.

How may water-waves be made on a larger scale?—By tossing pebbles into the water of a quiet lake or pond we may cause circular waves which spread away farther and farther from the place where the pebble was

dropped. By watching the motion of the water in these waves we may easily study the character of such vibrations.

In what direction does the water really move?—While looking at the growing circles of water started by the pebble it is most natural to think that the water is moving just as it appears to be—outward in all directions; and yet it is easy to show that it is not.

Little sticks and straws upon its surface would be carried along outward too, if such were the motion of the water, but we find that all the sticks and straws will do is simply to *rise* and *fall*, which shows that the real motion of the water is *up* and *down* only, and not outward from the pebble as it appears to be.

How is the motion in the billows of the sea?—The waves of the sea are of the same nature. The force of the wind, however, drives the water along at the same time that it is vibrating up and down. But the billows roll long after the wind has ceased to blow, and even they, at such times, are not able to carry along the bits of wood and other light bodies that may be floating upon them. Each wave will seem to roll out from under all such bodies, and let them down into the furrow to be lifted again by the next; and this shows that the real motion of the water is simply a motion up and down.

Does the air vibrate?—The air is so elastic that it yields to every force, even the very slightest, and then afterward springs back again. On this account it is in a state of vibration all the time. We can not stir a hand without causing the air to vibrate. It is made to tremble by every breath we exhale, and it quivers at every motion of our lips.

Start here Monday, Nov. 9, 1891.
24/13.

SOUND.

How is the sound of a piano-wire produced?—If we look carefully at a piano-wire while it is giving its sound we can often see that it is in motion; its appearance will be much like that shown in Fig. 27. And even if its delicate motions can not be *seen*, they may often be *felt* by placing the finger very gently upon the wire, or *heard* as a violent clatter if a knife-blade be used instead of the finger. The fact is that the sound of the wire is produced by these rapid vibrations.

Are other sounds produced in the same way?—By laying the finger gently upon the head of a drum a tremulous motion will be felt whenever the sound of the drum is heard. And in Fig. 29, while the motion of the little ball shows that the glass beside it is vibrating, a ringing sound is at the same time heard, and whenever a bell of any kind is ringing it may be shown that it is also vibrating. A body always vibrates when it emits a sound; all sounds are produced by vibrations.

Do all vibrations produce sound?—When a cord is long and not too tightly stretched (Fig. 27), its vibrations may be easily seen, but no sound will be heard.

A sudden motion of the hand puts the air in vibration, but gives no sound.

These and many other illustrations which might be given teach us that not all vibrations produce sound.

What is the reason that some vibrations do not produce sound?—If we make the string, Fig. 27, vibrate *faster and faster*, by increasing the weight which stretches it, we shall very soon be able to hear a sound which it gives, and then if the weight be made less again the sound becomes inaudible. This shows that when the sound is not heard the vibrations of the cord are *too slow* to produce it. Some vibrations do not produce sound because they are too slow. The slowest vibrations that may produce sound are at the rate of 16 a second.

Is there another reason why vibrations do not produce sound?—A string or wire may be made so short and tense that its vibrations can not be heard. It then vibrates so very fast that no sound is made by its motion. Some vibrations are too fast to produce sound. The most rapid vibrations that can be heard are made at the rate of 38,000 a second.

What are sound-vibrations?—All vibrations between the limits of 16 a second and 38,000 a second may be called *sound-vibrations*. No others ought to be so called because, if any are either slower than 16 a second or swifter than 38,000 a second they can not be heard.

Is this true for all persons?—There are persons, however, to whose ears these limits will not apply. Some ears are more sensitive than others; they can hear sounds that others can not. The squeak of a bat is made by very rapid vibrations, and it is said that there are persons who can not hear it at all. The same thing may be said of the chirping of a cricket; two persons sitting in the presence of one of these animals may have ears of such different power that while one is annoyed by the shrillness of the cricket's voice, the other may not know that there is any noise

produced. The limits named must, therefore, not be taken as absolute.

Will sound-vibrations pass through air?—We could not hear the sound of a distant bell if the air did not bring its vibrations to our ears. But we may describe more carefully the way in which the sound comes to us. In the first place, the ringing bell is itself vibrating, as we know, and by these vibrations the air which is in contact with the metal is made to vibrate also. This air causes another portion beyond it to vibrate, and that in turn gives motion to another portion still farther away, until finally the air in contact with the ear is made to vibrate and then we hear the sound. Very quickly after the hammer strikes the bell, all the air between it and the ear is put in motion, but not until this motion has traveled, step by step, from the bell to the ear, can the sound be heard. Such transmission of vibration is an *undulation* or *wave*.

In this way all sounds made in the air travel from place to place. In speaking, our lips intrust their messages to the air and the air carries them to the ears of our friend and delivers them with the most perfect accuracy.

Will sound-waves pass through water?—Let two stones be struck together under water and the sound of the blow will be distinctly heard above the surface. Or if the head is plunged beneath the surface while the blow is struck, the sound will be heard more distinctly than in air; its loudness will be likely to surprise the hearer. These things show that sound-vibrations pass through water with great facility.

Will sound-waves pass through solid bodies?—To show that sound-vibrations also pass through wood, let the ear be placed upon one end of a long table while a pin is drawn across the other end. One who tries this experiment for the first time may be astonished to hear a sound so loud as the scratch of the pin will be. The sound-vibrations in this case travel through the wood of which the table is made.

The power of solids to convey sounds is also illustrated when boys at the station, waiting for a train of cars, put their ears upon the iron track to learn whether it is coming near. The sound of the train can be heard much farther through the solid iron than through the air.

"The American Indians understand that solid bodies, even the earth itself, convey sound with great facility. When these wild and artful people suspect that enemies are approaching they apply their ears close to the ground in order to discover the noises made by the footsteps of their foes when too far off for the sound to be conveyed through the air."

Can sound-waves pass through a vacuum?—We have seen that sounds can pass through solids, liquids, and gases, but we must remember that they can not pass unless one or another of these forms of matter is present.

This may be shown by experiment. A bell may be placed in the receiver of an air-pump, and be so fixed that while there it may be struck. Before the air is exhausted its ringing may be loud and clear, but long before the air is all taken out it will be almost too feeble to be heard at all. Sound can not pass through a vacuum.

What is the velocity of sound in different substances?—Sound travels faster in some substances than in others. By very careful experiments it has been found that in air whose temperature is 61° F, sound goes

at the rate of 1,118 feet a second. It would travel faster through warmer air and more slowly in that which is colder.

In water, sound travels faster than in air; its velocity is about 4,714 feet a second.

In solid bodies the velocity of sound is still greater. In pine wood, for example, it travels at the rapid rate of 10,900 feet a second.

Do all kinds of sound go with the same velocity?—In air all sounds travel with the same rapidity. We may, for example, while listening to the music of a distant band, notice that the heavy sound of the drum and the shrill notes of the fife, made at the same moment, reach the ear together, and this shows that they must come with equal swiftness.

The same thing is true of all sounds whatever. Loud sounds and low sounds, the sweetest and the harshest alike, travel through the air at the rate of 1,118 feet a second. The overpowering roar of the thunder can not outrun the delicate song of the sparrow. In any medium all sounds travel with equal velocity.

How can we measure distances by sound?—If sound goes through air at the rate of 1,118 feet each second, it will go twice that distance in two seconds and ten times that distance in ten seconds; so that we need only to multiply 1,118 feet by the number of seconds to tell how far the sound has come.

A man is chopping wood in the distance, and you wish to know how far he is away: watch the motions of his axe and listen to the sound of the blows. You will hear the sound while the axe is over his head. The sound is made when the blow is struck, and it takes as long for the sound to come to you as it does for the axe to be lifted.

If it is one second between the time you see the blow and the time you hear the sound, then the woodman must be 1,118 feet away.

Give another example.—In a similar way you may tell how far off a flash of lightning occurs. The sound of thunder is made when the lightning is seen, but it is not often heard until several moments afterward. If you can count the seconds between the flash and the roar you may multiply 1,118 feet by the number, and this will give the number of feet to the place where the lightning occurred.

Upon what does the loudness of sound depend?—The harder one strikes a piano-key the louder the sound of the note will be, but all that the heavier blow does is to make the piano-wire vibrate through greater distances. In all cases the loudest sounds are caused by vibrations through the greatest distances.

Now the distance through which the vibrating particles swing back and forth is called the *amplitude* of vibration, and hence we may say that the loudness of sound depends upon the *amplitude* of the vibrations which produce it.

The harder one strikes a bell the louder it rings, because the heavier blow causes the particles of the bell to vibrate through greater distances, or, in other words, to have a greater amplitude of vibration.

What effect does distance have upon the loudness of sound?—The deafening roar of a cataract when heard through a distance of several miles becomes a gentle murmur, and the deep-toned thunder, if made too far away, can not be heard at all.

A powerful human voice may be heard at a distance of about 700 feet; at greater than that distance it is generally too feeble to be heard.

Sounds, however loud when near at hand, die away in the distance until they become inaudible.

Why is this?—This is because the amplitude of the vibrations of the air grows less and less as the distance is greater and greater, until at last it is too little to affect the ear.

How can we illustrate this?—When a pebble is dropped into quiet water, the height of the circling waves is greatest near the center where the pebble is dropped, and grows less and less as they spread outward, until at last we can not see the waves at all. So when a bell is struck, the amplitude of the air-waves near to the bell is greatest, and it grows less and less as the waves spread outward in all directions from the bell, until at last it is so little that the sound can not be heard.

Which will convey sound farthest, solids, liquids, or gases?—In solid bodies the vibrations diminish slowly, and on this account sounds may be heard through them at long distances. In liquids the vibrations diminish more rapidly than in solids, so that through them sounds can not be heard as far. In gases the vibrations die out still faster, and hence sounds can not be heard as far in them as in either of the other forms of matter.

We now see why the sound of a coming train of cars can be heard sooner by placing the ear to the iron track. The solid iron conveys the sound to the station, but in the air the vibrations die away before they get there.

Can sound be heard farther in air at some times than at others?—When the air is dense, as in a cold still winter morning, or damp, as it often is in a still June evening, we all know how much more distinctly distant sounds can be heard than at other times. The rattling of carriages, the laughing of children, the songs of birds, and

a thousand other sounds, many of which at other times would not be noticed, are heard with surprising clearness in still damp summer evenings.

What is the law?—But whether a sound can be heard through a distance great or small, the rapidity with which it dies away is governed by the following law:

The intensity or loudness of sound is inversely as the square of the distance from its source.

We understand by this law that at twice the distance sound will be only one fourth as loud; or at one half the distance it will be four times as loud.

Will a tube convey sound?—If we put our lips to one end of a long tube of metal, or even of pasteboard, while a friend puts his ear at the other end, we find that even a gentle whisper will be very distinctly heard.

A gentleman in the city of Paris tried the experiment with one of the water-pipes of that city, and found that a word spoken in a very low tone was heard by a friend three fourths of a mile away, while, as we have already learned, a powerful voice in the free air would not be heard more than one fifth of that distance.

Why can sounds be heard farther in tubes?—The reason that sounds can be heard so much farther in tubes than in free air is that the tube keeps the vibrations from spreading in all directions outward as they do in the atmosphere. They are all collected in the tube and sent forward together, and they will not die away as fast as when allowed to scatter in all directions in the air.

What are such tubes called?—Such tubes are called *speaking tubes.* They are often placed in dwellings so that the mistress may talk with her servants even while they are in different and distant rooms. They are also placed

in large hotels for a similar purpose, and in large manufacturing establishments they are very common and a great convenience.

What is an echo?—Who, after loudly uttering some word or sentence, has not at some time heard the sound of his voice coming back to him from a distant wood, or perhaps from the wall of a distant building? A part of the last word spoken, if not the whole of it, and sometimes more words than the last one, may be heard as distinctly as if some mimic were shouting back what he had heard. Such sounds are called echoes.

How is an echo produced?—When we throw a ball perpendicularly against the floor it bounds directly back to the hand. In the same way when the sound of our voice strikes perpendicularly against a distant wall, it bounds back to us and we catch it in our ears, and thus hear the word which we uttered, as an echo.

Or, if we throw a ball obliquely against the floor it bounds away obliquely from us: we can not catch it, but it may be caught by another person standing in the right place. In much the same way if a sound strikes obliquely against a distant wall it will be thrown obliquely away from it, and a person standing in its path will hear the sound as if it came to him obliquely from the wall. It is in this way that we hear the echoes of sounds which are not made by ourselves.

What is reflection of sound?—When sound is thrown back from a surface against which it strikes, it is said to be *reflected*.

Mention some remarkable echoes.—An echo in Woodstock Park repeats seventeen syllables distinctly. Another near Milan repeats a single syllable thirty times: in this case the sound is thrown from one reflecting surface to another many times, and each reflection sends an echo to the hearer.

"Placing himself close to the upper part of the wall of the London Coliseum, a circular building 130 feet in diameter, Mr. Wheatstone found a word pronounced to be repeated a great many times. A single exclamation sounded like a peal of laughter, while the tearing of a piece of paper was like the patter of hail."

MUSICAL SOUNDS.

What was Galileo's experiment?—Galileo passed the back of his knife-blade quickly over the rough edge of a coin and produced a musical sound. You may repeat his experiment easily, or in the absence of a coin with ridges upon its edge, you may use a piece of one of the heavier strings of a violin or piano, which are wound with fine wire; or, indeed, if there is nothing better at hand, the edge of a small file may be used. If you pass the blade slowly over one of these rough surfaces a series of unpleasant taps will be heard, but pass it swiftly and you will produce a shrill musical sound.

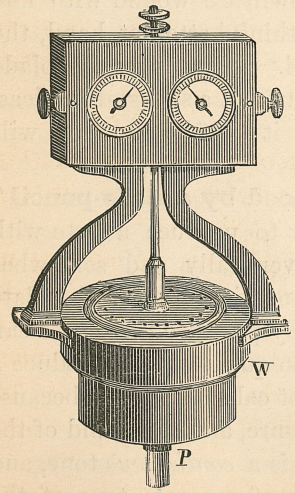
How may a note be produced by a slate-pencil?—"Every schoolboy knows how to produce a note with his slate-pencil. Holding it vertically and somewhat loosely between the fingers, on moving it over the slate a succession of taps is heard. By pressure these taps can be caused to follow each other so quickly as to produce a continuous sound. We must not call it musical, because this term is associated with pleasure, and the sound of the pencil is not pleasant." But it is a *continuous* tone, and yet we know that it is made up of separate taps of the pencil.

May other separate sounds be made to cause a musical sound?—Any sound whatever, repeated fast enough, will produce a continuous sound or a tone. To illustrate this curious fact still further, suppose a stiff card is held against the edge of a cog-wheel turning slowly; the card will strike each cog that comes around and every blow will be heard separately, but when the wheel turns swiftly the same blows, made faster, produce a continuous and shrill musical sound.

If a watch could tick fast enough, say 80 or 100 times a second, no one would be able to count the ticks, or even to hear them separately, for they would produce a steady musical sound.

Could the blows of a hammer upon an anvil be made fast enough and with regularity, they would produce a clear and powerful musical tone.

Fig. 31.



Even puffs of air when made in quick succession result in music. This interesting fact is shown by means of the siren—a very ingenious instrument which we must now describe.

Describe the siren.—In Fig. 31 this instrument is represented. A pipe, P, enters a wind-chest, W. The top of this chest is pierced with a circular row of holes. A disk of metal lies very near to the top of the wind-chest and is pierced with holes exactly corresponding with those in the chest itself. The disk is so fixed that it may be made to revolve very swiftly, and

the pointers, like the hands of a clock, seen at the top of the picture, are to tell the number of turns the disk makes in a second.

Now suppose the holes in the disk are exactly over those in the top of the chest. Then if a blast of air is forced through the pipe, P, into the chest, it can escape through the holes in steady streams; but let the disk be turned just a little so that its holes are not directly over the others: by this means the holes in the chest will be closed so that the streams of air can not escape. As the disk revolves the holes in the chest will be rapidly opened and shut, and the streams of air will, in this way, be cut up into puffs.

When the disk turns slowly the separate puffs may be heard, but when it goes rapidly these same puffs produce a musical tone of great purity.

What is necessary, then, to produce a musical sound?—All that seems necessary to produce a musical tone out of any sound whatever is that the separate pulses be made with sufficient regularity and swiftness.

What is meant by the pitch of musical sounds?—To distinguish musical sounds as being high or low, the term *pitch* is used.

Some sounds, like the gravest notes of an organ, are so very low that we can scarcely hear them, while others, like the highest notes of the piano, are so very high that they are very far above the reach of any human voice. Between the highest and the lowest there may be a multitude of musical notes whose only difference is a difference in *pitch*.

Upon what does pitch depend?—If we take several strings all alike, except in length, we shall find that the

shortest string always gives the highest sound. And now if we remember that the shortest string always vibrates the fastest, we see that the highest tone is the one that is made by the most rapid vibrations.

This is true in all cases. The pitch of musical sound depends entirely upon the rapidity of vibration.

Upon what does the rate of vibration of a string depend?—The rapidity of vibration of a string or wire, as we learned while studying the subject (p. 71), depends upon the *length* of the string, its *tension*, and its *weight*.

How then may we vary the pitch of the sounds of strings?—If we change either the length of the vibrating string, or its tension, or its weight, we change the pitch of the sound it produces.

To shorten the string makes the tone higher; to increase the tension also makes the tone higher; but to increase the weight of the string makes the tone lower.

How is the pitch of the sounds obtained in the piano?—In the piano the sounds are made by the vibration of wires. These wires are of different lengths and also of different weights; the shortest and the lightest giving the highest tone. Now one end of each wire is wound around a screw, and by turning the screw in one direction the wire is tightened and the pitch raised, but by turning it the other way the wire is loosened and the pitch lowered.

How is the pitch obtained in a violin?—The violin has four strings, each having a weight different from the others, the lightest string giving the highest note. Each string is wound upon a "key" by which it may be tightened or slackened, the tighter string giving the higher note. They are all of the same length, but the player

changes the length of the vibrating part of each at pleasure by pressing a finger upon it at any desired point.

By having the right difference in the weight, the tension, and the length of the strings, the correct pitch of the notes is obtained.

How is the sound of the organ produced?—In the organ the musical sounds are caused by vibrations of columns of air. A large bellows is kept full of air; the organist, by pressing the keys of the organ, opens the way from this bellows into one or more of the many pipes of the instrument, and jets of air going into the pipes at the bottom, make the air throughout their whole lengths vibrate, and these vibrations produce the musical sounds.

Upon what does the pitch of organ-tones depend?—The pitch of the tone in an organ depends on the length of the organ-pipe. The shorter the pipe the higher the pitch will be.

The lowest note used in music is made by an organ-pipe, open at the top, whose length is 32 feet. If the pipe is closed at the top, a note of the same pitch will be made by a pipe 16 feet in length. The highest notes are made by pipes which are only a few inches long.

Start here Nov. 11, 1891.

LIGHT.

What are luminous bodies?—Luminous bodies are those which produce light. The sun is a luminous body because it shines by light which itself produces. The flame of a candle, and a red-hot iron ball, are also luminous bodies for the same reason.

What are non-luminous bodies?—Non-luminous bodies are those that do not produce light. If they shine at all it is because they first receive light from some other source and then throw it off again. A piece of rock or of wood, a flower, a cloud,—all these are non-luminous bodies. The moon is also non-luminous, for while it shines with a steady and bright light, yet it produces none itself. What we call the moonlight is light which goes from the sun to the moon first, and is then thrown from the moon to us.

What are transparent and opaque bodies?—Some bodies, like glass and air, allow light to pass freely through them; all such are called *transparent* bodies. Others, like iron and wood, forbid the passage of light through them; such are called *opaque* bodies.

Is any substance perfectly transparent?—We do not mean that a transparent body will allow *all* the light that falls upon it to go through. The air, for example, which is one of the most transparent of all things, does not let all the sunlight come through it. One can often look

directly at the sun, rising in the morning or setting in the evening, without doing any injury to the eye, but if the air did not shut out a large portion of the sun's light a single glance would blind him. Perhaps no substance exists which is *perfectly* transparent.

Is any substance perfectly opaque?—On the other hand, small quantities of light will pass through wood and even through gold, for we all know that it is easy to see through a thin shaving of almost any kind of wood, and, if a piece of gold-leaf is at hand, we may hold it between the eye and a window and see that light comes through it: this light is green.

What are rays, beams, and pencils of light?—A *ray* is a single line of light. Several parallel rays together form a *beam* of light.

The ray of light is quite too delicate a thing to be obtained in practice; the smallest line of light which it is possible to use is made of many rays; it is a beam.

A *pencil* of light is a collection of rays that are not parallel.

In what direction does light go from a luminous body?—If a lamp is suddenly lighted in the center of a dark room, every part of the room will be instantly made light. This shows that the light goes from the flame in all directions. In the same way light is given from a glowing coal, from a red-hot iron, from the sun, indeed, from all luminous bodies, in every possible direction at once.

Does it move in straight lines?—In order to show by experiment whether the path of light is straight or crooked we need a darkened room. It is easy to darken a room by closing the shutters, and at the same time, if

need be, hanging shawls or blankets over the windows. If a small hole is made in one of the shutters to let the sunlight through, the path of the sunbeam in the room may be distinctly seen. If the air is sprinkled with chalk-dust the beam is peculiarly bright and beautiful, and no artist could possibly draw a line so absolutely straight as it is seen to be.

We often see such beams coming through our half closed window-shutters and streaking the dusty air of our rooms with bars of light,—beautiful illustrations of the fact that light always moves in straight lines.

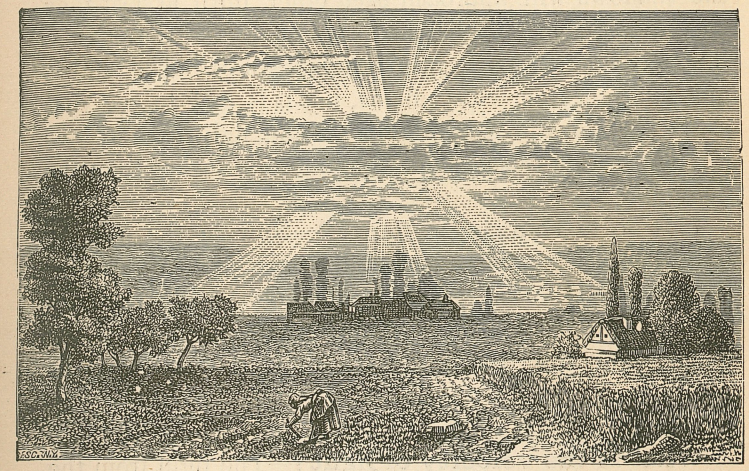
What are other illustrations of this fact?—When the sun is sinking behind clouds in the western sky, it often presents an appearance which is very well shown in the picture (Fig. 32), and which is sometimes described by saying that the sun "draws water." Is it possible that any one ever believed the streaks he saw were really streams of water being pulled up by the sun? We know now that they are beams of light from the sun, which is shining through openings in the clouds. They are made in just the same way as are the beams of light seen in our rooms when the sun shines through openings in the window-shutter.

How are shadows made?—It is upon the same principle that shadows are made. To illustrate, just put a book at a convenient distance in front of a lamp-flame. Now some of the rays of light fall upon the book, and can not go farther, but others just graze the edges of the book and pass in *straight lines* onward, so that behind the book and reaching to the opposite wall is a space from which the light is shut out. *This space which is deprived of light is the shadow* of the book.

We are apt to call the black spot on the wall the shadow,

but the shadow really reaches from the book to the wall; it is all the space behind the book from which the light is shut out, and the black spot on the wall is only one end of it.

Fig. 32.



Of what two parts is a shadow composed?—If we examine the end of the true shadow of the book as it appears upon the wall, we may notice that there is a dark middle part, and then a border all around this, which is much lighter. One can hardly fail to see these two parts by examining the shadows made by objects around the evening lamp. There is in every shadow a dark middle part surrounded by another lighter portion. The dark middle part is called the *umbra*, and the lighter portion is called the *penumbra*. These parts reach throughout the whole length of every shadow.

How are they formed?—A very easy experiment will explain how these two parts of a shadow are pro-

duced. Place two lamp-flames on a table near each other, and hold a lead-pencil or a narrow strip of wood between the flames and a sheet of paper, at some distance from them. Two distinct shadows will be seen, one cast by each light. Now move the pencil nearer to the paper, the shadows will approach each other, until at last they overlap and form one, in which the umbra and the penumbra may be seen with surprising clearness. The umbra gets no light from either flame, but it is easy to see that every part of the penumbra is getting light from one or the other. On this account the umbra is darker than the penumbra.

Is it so with a single flame?—Now in the shadow cast when a single flame is used, the outer parts are getting light from *one edge or another of the flame*, while the middle part is getting no light at all from any portion of the flame. For this reason the umbra is darker than the penumbra.

What is the velocity of light?—The light from the flash of a gun in the distance comes to us so very quickly that it is impossible to measure the brief time it takes. So swiftly does light travel, that, could it move in curved lines, it would go around the world more than seven times in a second! Its rate of motion or velocity is about 186,000 miles a second.

It will, of course, be interesting to know how a velocity so very great could be measured. It was first done by the Danish astronomer, Römer, about two hundred years ago.

How was the velocity of light found?—This gentleman, by observing the eclipse of one of Jupiter's satellites, found out how long it takes light to go across the

orbit of the earth, and he then divided that distance by the number of seconds, and so found out how far the light could go in one second.

Explain the operation more fully.—The time when an eclipse of Jupiter's moon is to begin is exactly known, as it would be seen when the earth is in that part of its orbit which is nearest to Jupiter. Now if the earth is in the opposite part of the orbit, the eclipse will not be seen to begin at the moment at which it is predicted, but 16 minutes and 36 seconds, or 996 seconds afterward. It is seen by light which comes from it, and the reason it begins late is that the light has so much farther to come. In fact it takes the light 996 seconds to go across the orbit of the earth. The distance across is about 186,000,000 miles, and 186 millions divided by 996 gives about 186,000 for the number of miles that light can travel in one second of time.

How does distance affect the intensity of light?—The nearer a body is to the source of light, the brighter or more intense will be the light that falls upon it.

Let us study this subject more closely by experiment. We may take a sheet of paper, or, what is a little better, a square of stiff card-board, and hold it half way between a lamp-flame and the wall of a room. If we measure the shadow on the wall, we find it to be just twice as long and twice as wide as the card-board, and hence its surface is just four times as large as that of the board.

Now if the light that falls upon the card-board could go to the wall it would cover the whole surface of the shadow, and be spread over a surface four times as large as that on which it does fall. Being spread over four times as much surface it can be only one fourth as bright.

We see from this experiment that at 2 times the distance from the flame the light is only one quarter as intense. If the distance is taken 3 instead of 2, the intensity would be only one ninth. The law is this:

The intensity of light varies inversely as the square of the distance from its source.

The light of the stars is dim, but if any one of these glimmering points could be brought as near to us as the sun, it would be more dazzling than that body is to us. Or, if the sun could be carried out as far as the stars, it would be no brighter than they.

How can we see objects?—A luminous body is seen by means of light which comes directly from it into our eyes. It is the light which *comes from* a red-hot iron ball which enables us to see it.

We see non-luminous bodies also by means of light which comes from them: it is impossible to see any object that does not send light into the eye.

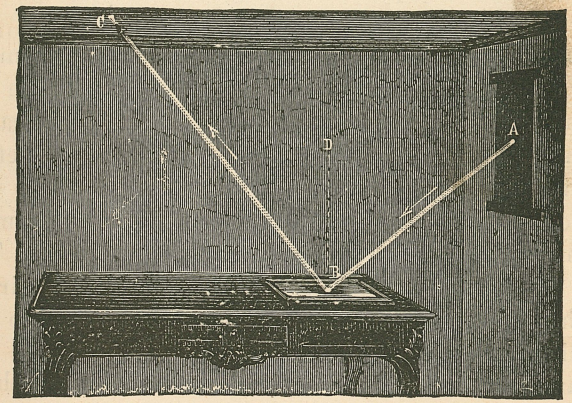
How can this be true of non-luminous bodies?—Non-luminous bodies have no light of their own to send to the eye, but they receive light from luminous bodies, and throw it off again into the air. This light which they throw off may enter our eyes, and by this means the body becomes visible.

All non-luminous bodies are invisible in a very cloudy night, because no light from the sun or moon or stars falls upon them, and they can send none to the eye. All objects in our room disappear instantly when the lamp is extinguished, because no light then falls upon them, and we therefore get none from them.

What is reflected light?—This light which is thrown off from non-luminous bodies is called *reflected* light.

What experiment can illustrate reflection of light?—Let a beam of sunlight into a darkened room through a hole A, Fig. 33, in the shutter of a window, and make it fall upon a looking-glass. This beam will bound off, or be reflected from the glass, and go up to the ceiling, where it will form a bright spot C. Let the air of the room be sprinkled with dust, and the beams of light will

Fig. 33.



be shown as clearly as they are represented in the picture, which is a very good picture of the experiment.

What are important parts to notice here?—It is very necessary to understand clearly the use of certain terms which are applied to certain things represented in this figure. There is first the beam AB, which *falls upon the reflecting surface*, and is called the *incident beam;* and then the beam BC, which is *thrown from the reflecting surface*, and is called the *reflected beam*. The point B is called the *point of incidence*.

And now, if we suppose a perpendicular BD to be

erected, we have two angles made, one, ABD, the angle between the incident beam and the perpendicular, is the *angle of incidence*; the other, CBD, the angle between the reflected beam and the perpendicular, is the *angle of reflection*.

What is the law of reflection?—Now these two angles are exactly equal in this experiment: they are always so. The law of reflection states that the angle of reflection must be equal to the angle of incidence.

What are mirrors?—Some bodies reflect light much better than others. Very little is reflected from the surface of rough iron, for example, while a great deal is thrown from the surface of new tin. Those which reflect light most freely are called *mirrors*.

A common looking-glass is the most familiar example of a mirror, but other forms are almost as common. The inside surface of a bright silver spoon is a good mirror, and the outside surface also, because from both these surfaces light is very freely reflected.

What are three forms of mirrors?—There are three forms of mirrors which need especial notice:

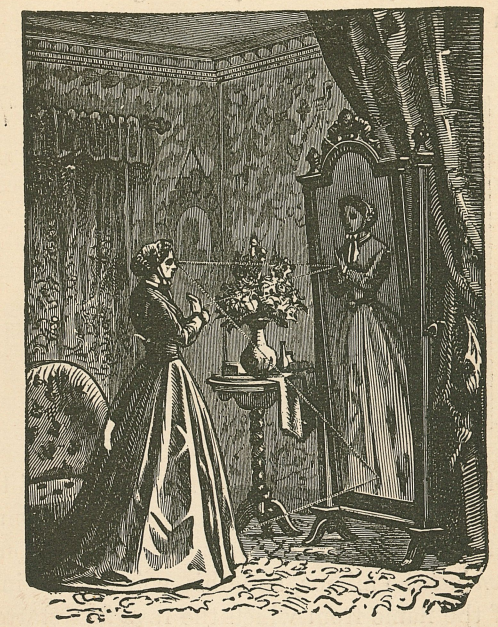
First, the *plane* mirror, one whose surface is like that of the looking-glass, plane or flat.

Second, the *concave* mirror, one whose surface is like that of the inside of the silver spoon, hollowed or concave.

Third, the *convex* mirror, one whose surface is like the outside of the silver spoon, rounded or convex.

What effect do plane mirrors cause?—If light from any object falls upon a plane mirror, and after reflection enters our eyes, we see an image of the object (Fig. 34). It appears to be behind the mirror, and just as far behind it as the object itself is in front (Fig. 35).

Fig. 34.

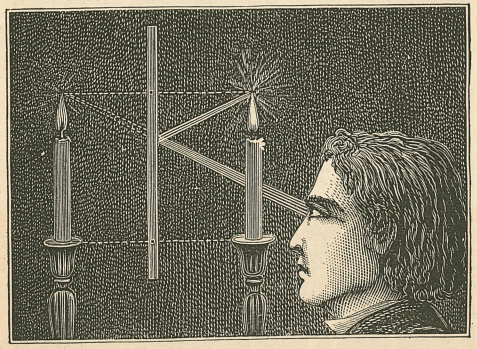


Give examples.—Our own image seen in a looking-glass is the most familiar example of this effect, but looking down into the water of a well or of a lake will show the image just as perfectly. The surface of quiet water is indeed a very perfect plane mirror, and forms images of all objects above it with wonderful clearness. How beautiful are the pictures of the mansions and shrubbery along the bank of a river, or near the shores of a lake, as we see them presented in the still water between us and them!

How are images formed?—The way in which this

curious effect is produced may be understood by studying Fig. 35, which represents a boy looking at the image of a candle in a looking-glass.

Fig. 35.



Rays of light are shown going from the tip of the candle-flame to the mirror, and being reflected from it into the eye of the boy. These rays *appear* to have come from a point *behind* the mirror, and this point is the image of the tip of the flame from which the rays first started.

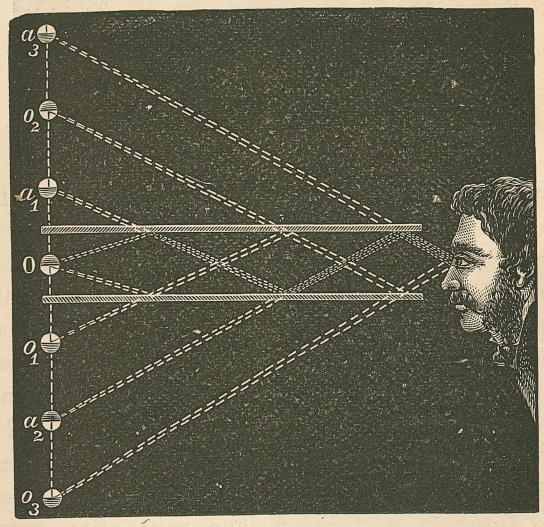
Now every point on the whole candle will send rays to the mirror to be thrown back into the same eye, and thus form an image of every point, or in other words an image of the candle itself.

And so, when a person sees his own image in a mirror, he may think of its being formed in the same way. He may think of rays of light going from *every point* on his person to the mirror, and thence, being reflected, coming into his eyes, and then he may think of his eyes tracing these rays right back, in the direction from which they last came, to points behind the mirror; these points make up the image which he sees.

How may more than one image of an object be made at once?—By using two looking-glasses several images of one object may be seen at once.

By placing two looking-glasses parallel to each other and near together, and then putting the eye at one end, while a ball or other object is put between them at the other, a large number of images of the ball may be seen. The picture, Fig. 36, shows how the light must be reflected

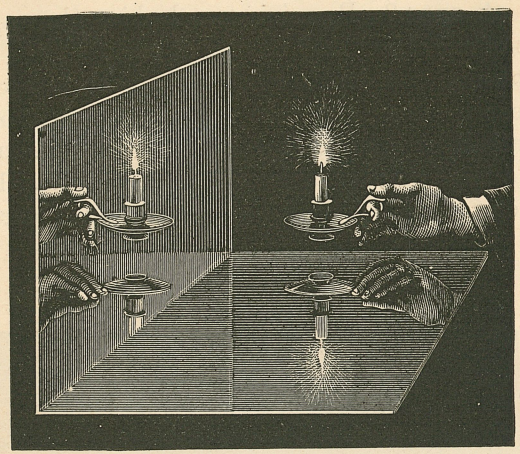
Fig. 36.



back and forth from one mirror to the other to make so many images.

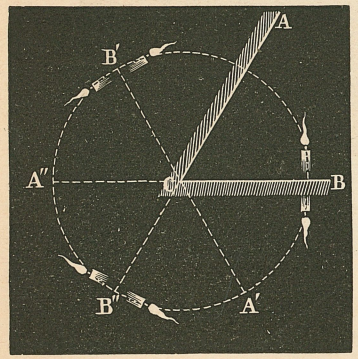
How may just three be formed?—By holding two mirrors at right angles (Fig. 37), any object placed between them will give three images.

Fig. 37.



How may five be obtained?—But if instead of being at right angles the mirrors are inclined, as in Fig. 38, making an angle of 60°, just five images will be formed.

Fig. 38.

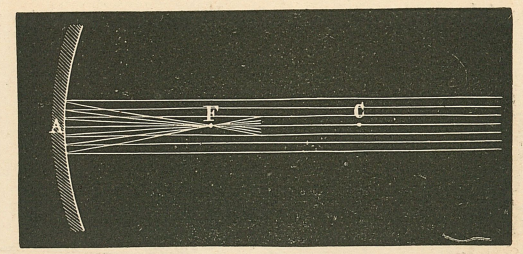


What is the effect of a concave mirror upon a beam of light?—Fig. 39 shows the effect of a concave mirror on parallel rays. The rays, after reflection, will no longer be parallel; they will converge and cross each other at the point F. This point is called the *focus* of the mirror. Any point where rays, after reflection, cross each other, is a focus; but when the mirror is held perpendicular to the path

of the beam, as in the picture, the focus is called the *principal focus.*

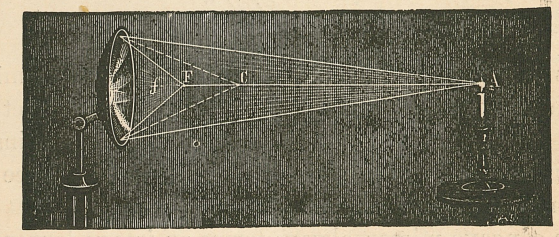
What is the effect of the concave mirror on diverging rays?—Let a candle-flame be held some distance

Fig. 39.



before a concave mirror (Fig. 40), and the light reflected will make a bright spot upon the finger or any thing else

Fig. 40.

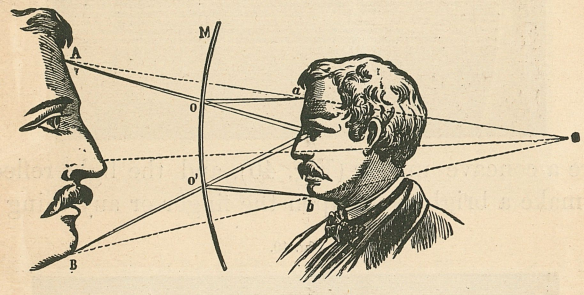


held at the point F. We see that while the rays from the candle are diverging, those which are thrown from the mirror are converging.

What effect does a concave mirror always produce?—In both these pictures we notice that the rays, after reflection, are brought nearer together than they were before, or, in other words, that they are *collected* by reflection. A concave mirror always makes the rays go on nearer together after reflection than they did before.

Describe the image formed by a concave mirror when an object is placed very near.—By holding one of these instruments very near to the face, a person can hardly recognize himself in the immense image which he sees. The picture (Fig. 41) represents a concave mirror, M, with a young man standing very near to it; his

Fig. 41.



face is supposed to be between the focus and the mirror. The image formed is much larger than the object, and seems to be almost upon the surface of the mirror, instead of being as far behind it as we are accustomed to see it in a common looking-glass.

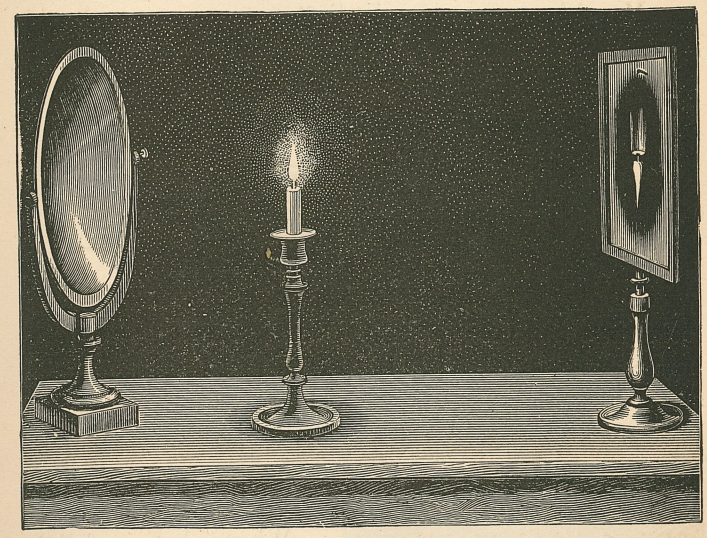
The concave mirror always forms an image larger than the object if the object is very near to it.

Suppose the object is moved away from the mirror?—If a candle is put a little farther away from the mirror than the focus, a still more curious effect will be produced. The image will not appear behind the mirror at all; it will be in front of it and farther away than the object itself, and, curiously enough, always bottom upward, or inverted.

The picture (Fig. 42) represents the experiment. The

image could not be seen if a screen were not put in just the right place to receive it, because no light would come

Fig. 42.



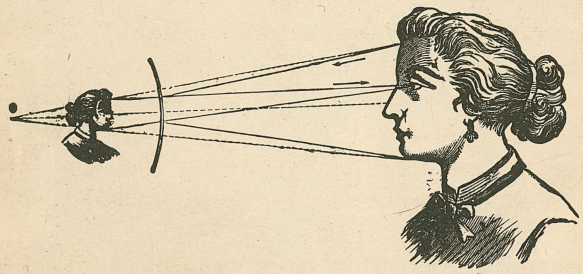
from it to our eyes. The screen receives the light which forms the image and reflects it to the eye.

Now let the object be moved still farther away.—If the candle is carried still farther away from the mirror, the image will move up toward it and grow smaller. At length the object and the image will be at equal distances from the mirror; they will then be of equal size, but as the candle is carried out farther and farther the image will go nearer and nearer to the mirror, growing smaller and smaller all the time, until finally it appears only as a bright spot at the focus.

The concave mirror is the only form that can produce images in front of it, or that are inverted.

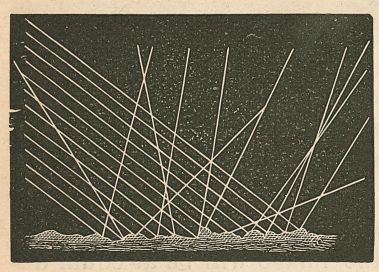
Describe the image by a convex mirror.—Fig. 43 shows the small image which is formed when a person

Fig. 43.



looks into a convex mirror. It is always, as we see it here represented, behind the surface of the mirror, erect, and smaller than the object.

Fig. 44.



How is light reflected from rough surfaces?—When a beam of light falls upon a rough surface it is reflected irregularly. This effect is shown in Fig. 44. The result is that the reflected light is scattered in every direction.

Do the rays obey the law of reflection?—When we say that the reflection is irregular, we do not mean that the rays are not thrown off according to the law of reflection. That law is never transgressed. Every ray

must be thrown in such a direction that the angle of reflection is equal to the angle of incidence. But on a rough surface, like that seen in Fig. 44, the reflecting points are not in regular order, and for this reason the reflected rays are not.

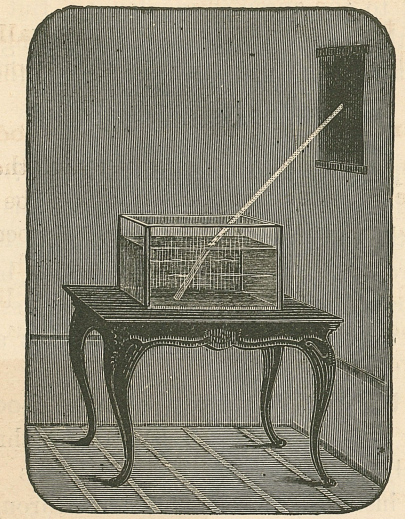
Do transparent bodies reflect light?—Transparent bodies do reflect light: we know this from the simple fact that we are able to see them; for we have learned before, that an object is visible only by the light which is thrown from it into our eyes. Glass and water are transparent bodies, and yet these bodies are able to reflect a great deal of light.

How do they differ from opaque bodies?—An opaque body does not allow light to pass through it; a transparent body allows the light to pass through it freely. For instance, we can not look through a piece of sheet-iron; it stops the light and reflects it, but we see distinctly through glass, because it can reflect only a part of all the light that falls upon it and allows the rest to come through.

Can this be shown by experiment?—Water is as transparent as glass, and we can easily show that water does not reflect all the light that falls upon its surface. The picture (Fig. 45) tells us at once how such an experiment is to be made. A glass vessel filled with water is placed so that a beam of sunlight coming into a dark room through a hole in a shutter can fall upon the surface of the fluid. The beam of light *can be seen* in its passage through the water.

All transparent bodies allow light to go through them in this way, but it is not always possible to see the path of the rays.

Fig. 45.



What else may be noticed in the experiment?—If the air in the room is a little dusty, the path of light from the window to the water, as well as through the water itself, can be seen, and then it will be noticed that the beam seems to be *broken* just at the point where it enters the liquid. This is also shown in the picture. The beam is perfectly straight while in the air, and perfectly straight while in the water also, but it is bent just where it passes from one into the other.

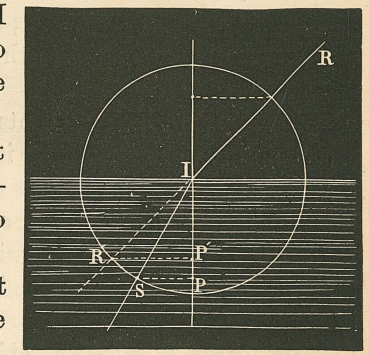
Is this always the case?—This bending of the rays of light in passing from one transparent substance into another generally takes place.

The light that comes through the windows into our houses is bent twice, once when it passes from the air outside into the glass, and again when it passes from the glass into the air in the room.

What is this bending of the rays called?—This bending of the rays of light in passing from one substance into another is called *refraction*.

What terms must now be understood?—To explain certain terms used in connection with the subject of refraction we must first suppose a line to be drawn perpendicular to the surface where refraction occurs, and to be extended both ways from it, or into both substances. In Fig. 46, for instance, we must suppose a line perpendicular to the water at the point I, where the light R I enters, and to reach up into the air and down into the water. Then we have,

Fig. 46.



The *incident beam*—that which falls upon the substance into which it is to pass, R I:

The *refracted beam*—that which passes through the second substance, I S:

The *angle of incidence*—the angle between the incident beam and the perpendicular:

The *angle of refraction*—the angle between the refracted beam and the perpendicular.

On what does the amount of refraction depend?—Some substances bend the rays more than others. The amount of bending depends upon the difference in the density of the two substances. If two substances could have exactly the same density, light would pass from one to the other without being bent at all, but if one is more

dense than the other, the bending will occur. For instance, water is more dense than air, so that light which passes either from air into water or from water into air, will be refracted.

What is the law of refraction?—If the rays are passing from one medium into a denser one the angle of refraction will be smaller than the angle of incidence, but if passing into one which is less dense the angle of refraction will be larger than the angle of incidence.

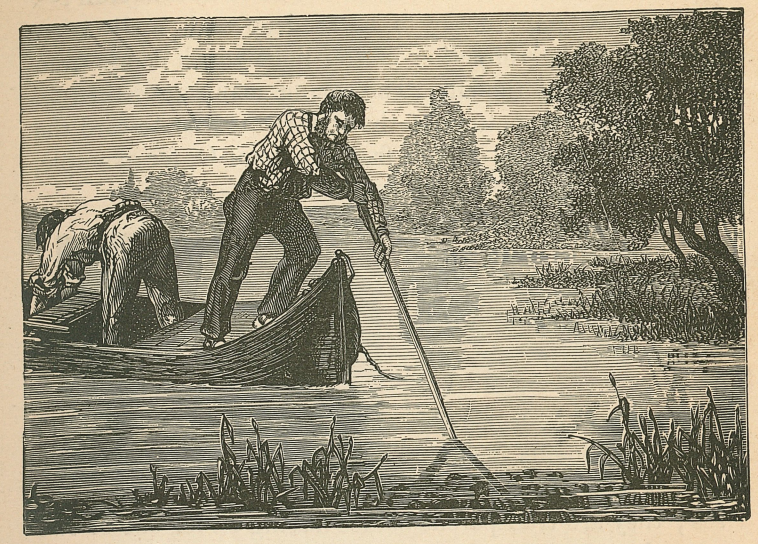
If, for illustration, the beam R I (Fig. 46) is the incident beam going from air down into water, it will be bent so as to go in the direction I S. Now it is easy to see that the angle S I P, in the water, or the angle of refraction, is smaller than the angle in the air, or the angle of incidence.

But suppose S I represents a beam going from the water up into the air above, it will be bent so as to go in the direction of I R. In this case the angle in the air is the angle of refraction: the angle of incidence is in the water. The light is passing into a less dense substance and the angle of refraction is larger than the angle of incidence.

How does a straight stick appear when partly plunged into water?—If a straight stick is plunged a part of its length into clear water it will look as if it were broken or bent just at the surface of the water. This effect is caused by refraction, and it is very common. Boatmen are especially familiar with it, since their oars always look bent at the point where they enter the water. (Fig. 47.)

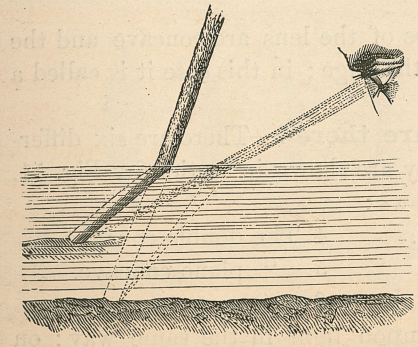
Why does the stick appear to be bent?—Of course the oar or stick is not bent, and it looks to be so only because the light that *comes out of the water from it* is bent

Fig. 47.



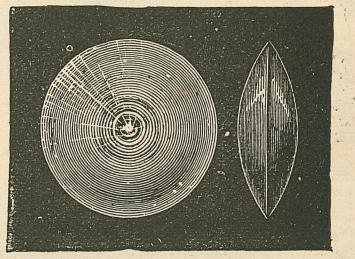
when it enters the air, and the part that is in the water will appear to be in the direction in which the light from it enters the eye. All this may be understood if you carefully examine Fig. 48, where the true place of the stick in water is shown by dotted lines, and two rays that come from the lower end of it are shown bent at the surface of the water, so as to enter the eye, which traces them back in *straight lines*, so that they seem to come from a point above the one from which they started.

Fig. 48.



What is another curious effect of refraction?—Water does not appear to be as deep as it really is on account of the refraction of the light which comes from the bottom into the air. The young man represented in Fig. 50 sees the bottom of the water lifted far toward the surface. The rays of light from the point O, for example, are refracted at the surface and by this means enter the eye as if they came from O′; and so the bottom at O seems to be at O′.

Fig. 49.



What are lenses?—The instruments used to refract light are called lenses; they are transparent bodies having either one or two curved surfaces.

Fig. 49 is a picture of one kind of lens. Looking at the side of the instrument it is circular; looking at the edge of it, it is found to be thicker through the middle; both sides are convex. This is called the *double convex* lens.

Sometimes both sides of the lens are concave and the middle is thinner than the edge; in this case it is called a *double concave* lens.

How many kinds are there?—There are six different forms of lens. They are shown in section by Fig. 51. They are named as follows:

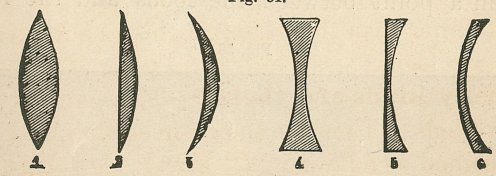
1 The double convex.	4 The double concave.
2 " plano convex.	5 " plano concave.
3 " meniscus.	6 " concavo convex.

The first three act upon light in the same way: on

Fig. 50.

this account only the first or double convex lens will be particularly noticed.

Fig. 51.

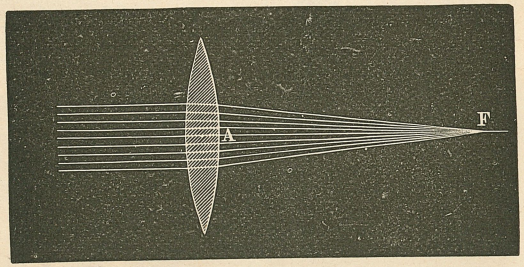


The last three are alike also in their effect, and we need give close attention only to the action of the double concave.

What is the effect of the convex lens on parallel

rays?—If a double convex lens is held in the path of a sunbeam, especially in a darkened room, the rays will not come out of it parallel: they will be so bent as to all come to one point, as we are shown by Fig. 52.

Fig. 52.

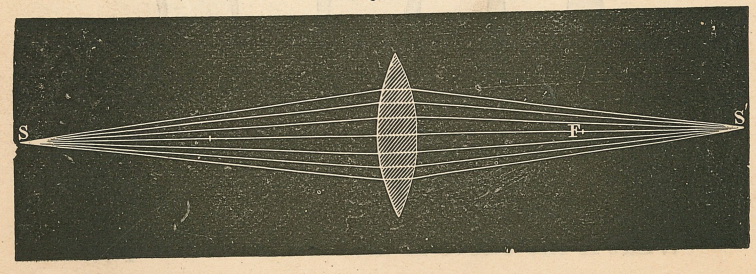


The point F (Fig. 52), where the parallel rays are collected, is called the principal focus of the lens.

What effect is produced on diverging rays?—We may suppose the rays to *go from* the focus to the lens: these rays (F A, Fig. 52) are diverging, and, as the figure represents them, they will be parallel after going through the lens.

But diverging rays are not always made parallel; indeed, they will not be unless they start from the focus. If they start from a point between the focus and the lens they

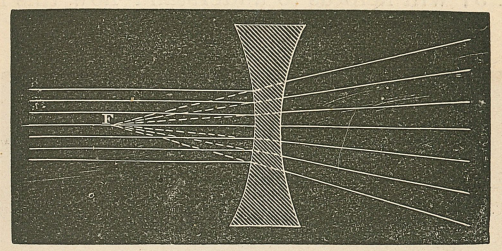
Fig. 53.



will diverge after going through, but the divergence will be less than before. On the other hand, if the rays start from a point farther than the focus from the lens, they will be converging after refraction. This case is beautifully shown in Fig. 53.

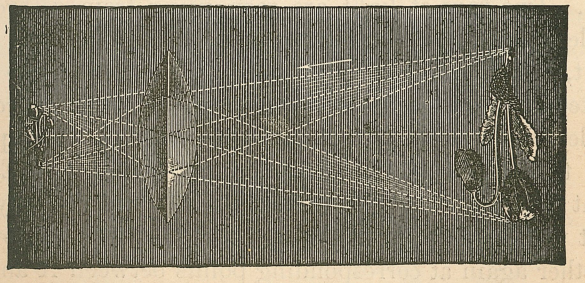
Does the concave lens have the same effect?—The concave lens has exactly the opposite effect. The rays after passing through a concave lens are separated instead of being collected.

Fig. 54.



This effect is well shown in Fig. 54, which represents a double concave lens refracting parallel rays of light.

Fig. 55.



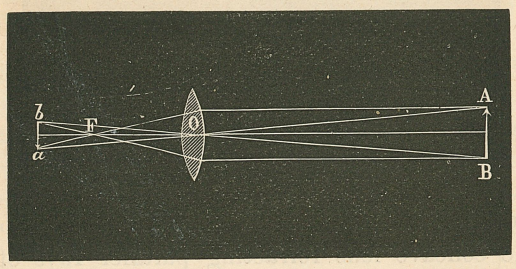
They are supposed to enter the lens on the side F, parallel to each other, but on coming out on the other side they

are diverging. All the concave lenses have the effect to separate rays by refraction.

Describe the image formed by a convex lens.—Most perfect and very beautiful images are formed by the use of convex lenses. If one of these instruments is held at a little distance from any object, a flower, for example, it will form an image which may be caught upon a screen placed in the right spot. This image will be on the other side of the lens from the object, and inverted (Fig. 55).

Explain the production of the image.—Fig. 56 and Fig. 57 will help us to understand how this image is

Fig. 56.



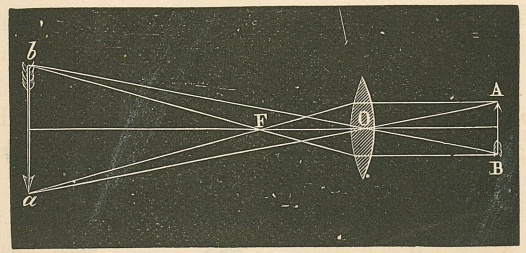
formed. They show a lens with a small arrow, *a b*, near to it. Two rays of light are seen going from *a* through the lens, and after refraction meeting again at A. This point, A, is the image of the point, *a*, from which the rays started. Two other rays are seen going from *b* through the lens and being refracted to the point B. This point B is the image of the other end of the arrow. Every point between *a* and *b* in the arrow will send off rays of light which, after going through the lens, will be brought together again at corresponding points between A and B, and all together they make up the whole image A B.

When will the image be larger than the object?

—If the image is farther than the object from the lens (see Fig. 56), it will be larger than the object.

When will it be smaller?—But if the image is nearer to the lens than the object is (see Fig. 57), it will be smaller.

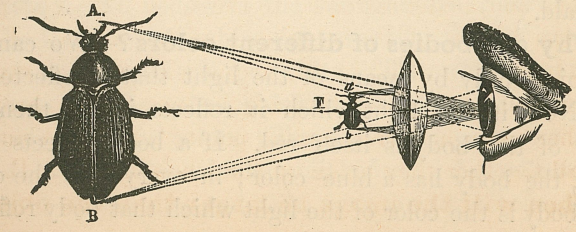
Fig. 57.



Whichever is farthest from the lens will be the largest.

Will the image ever be on the same side of the lens as the object?—In the cases thus far examined we suppose the object to be outside or beyond the focus of the lens. If the object is put between the lens and its focus, the image will be seen on the same side as the object. It will be erect, and very much larger than the object. In Fig. 58 this case is shown. A small insect is between the focus F, and the lens, and a person looking

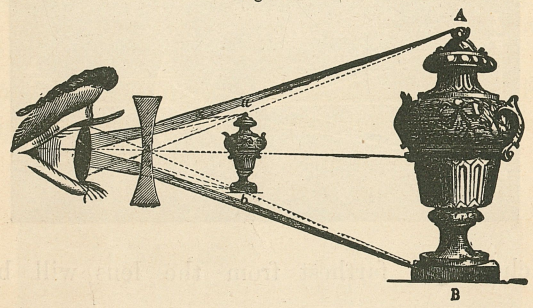
Fig. 58.



through the lens, instead of seeing the little creature *a b*, will behold its magnified image, A B.

What is the effect of concave lenses?—Concave lenses have just the opposite effect; they form an image always smaller than the object. In Fig. 59 we can see

Fig. 59.



how this is done. The light from the vase A B, after going through the concave lens, seems, to the eye, to have come from the smaller image *a b*.

Is all light of the same color?—The light which the sun sheds upon all things so freely, is said to be *white* light, but yet all light is not white. The light of some stars, for example, is as *red* as a flame of fire, while others shed upon us a delicate light as green as that of an emerald.

Why are bodies of different colors?—We can see an object only by means of the light that is reflected by it. Now, if the light which it reflects is red, then the color of the body is itself red. If a body reflects blue light, the body has a blue color; in every case the color of a body is the color of the light which that body reflects.

The meadows are green because the vegetation throws green light to our eyes.

What curious experiment will illustrate this?—"Fill a spirit-lamp with alcohol in which a large quantity of salt has been dissolved; on being lit it will be found to burn with a livid yellow flame." Let a room be lighted entirely by one or two of such lamps. "It should, if possible, be hung with pictures in water and oil colors, and the persons present ought to wear nothing but the brightest colors, and the table be ornamented with the gayest of flowers." Let the lamps be brought into this darkened room, and an astonishing appearance will be presented. "The furniture and every other object which the room contains will reflect but a single color. The brightest purple, the purest lilac, the liveliest green will be converted into a monotonous yellow. The same change will take place in the countenances of those present: every one will laugh at the appearance of his neighbor's face without thinking that he is just as great a subject of laughter to them."

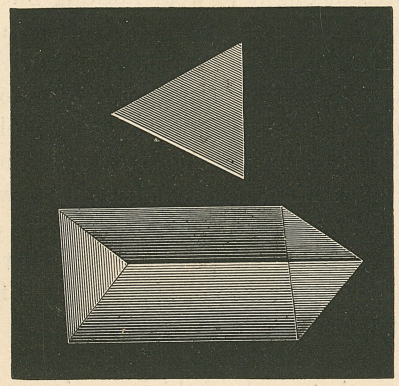
Nothing can, better than this experiment, show that bodies will seem to be of the color which they can reflect. When they receive only yellow rays, they can themselves be of no other color. And if any of them are not able to reflect yellow light, these will appear black.

Then why, in the sunlight, are not all bodies white?—All bodies in the sunlight are receiving only white light, and if white light was like that of any other color they would all be white. The white light must *contain all other colors* which bodies reflect. These bodies receive all these colors alike, and then each one makes choice of the color which it will reflect. A rose gets white light from the sun, and then from among all the colors it

contains, it reflects the red only. A violet reflects blue instead of red or any other, while the leaves of a tree reflect only the green rays of the white light which the sun sheds upon them.

By what instrument can sunlight be separated into its colors?—The instrument used in the arts to decompose light is called a *prism*. It is generally nothing

Fig. 60.

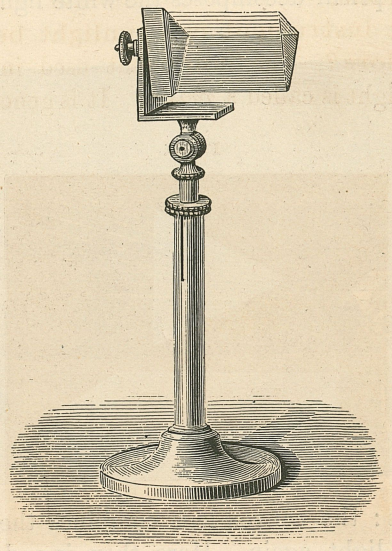


more than a triangular piece of glass, but it may be made of many other substances. Fig. 60 represents the prism, and Fig. 61 shows how this instrument is often mounted upon a stand to be convenient for use.

Describe the experiment with the prism.—Let a prism be held in a beam of sunlight as it enters a darkened room; the rays which come through the prism will strike the wall or ceiling of the room, or upon a screen, and form there a patch of beautifully colored light (Fig. 62). All the colors of the rainbow will be seen; and what is still more beautiful, if dust be sprinkled into the air of the room, these colors will be seen reaching all the

way from the prism to the wall. Rays of purest blue, of most delicate violet, of the brightest yellow, with others

Fig. 61.



of different colors, will be seen spread out like a fan from the prism through the dusty air.

This arrangement of colors formed from the sunlight which passes through a prism is called the *solar spectrum*.

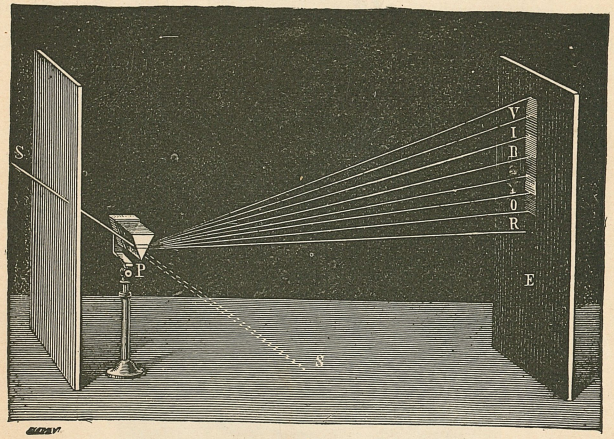
What are the colors in the solar spectrum?—There are *seven* colors in the solar spectrum. They are arranged in the following order: red, orange, yellow, green, blue, indigo, and violet.

These are the colors of which sunlight is composed, and the colors of all bodies in the world are produced by the mixture of two or more of these in different proportions.

Will the seven colors produce white light?—If

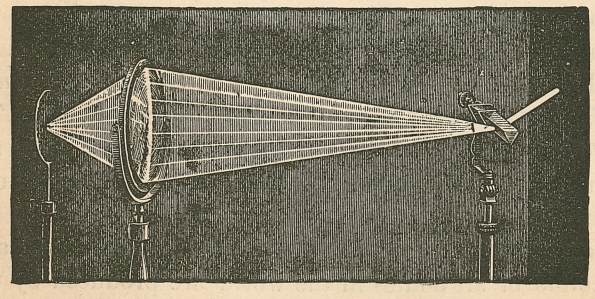
the colors formed by a prism are made to pass through a double convex lens (Fig. 63) they will be brought together again and the spot of light upon the wall will be white. The prism decomposes the white light and brings

Fig. 62.



out the colors: the convex lens combines the colors and makes white light again. Here, then, is a double proof

Fig. 63.



that white light is made up of the seven colors of the spectrum.

How is the rainbow formed?—In a shower of rain each drop of water is able to decompose the sunlight and give the different colors of the spectrum. This it will do if the sun is shining brightly at the time the drop is falling, and you will remember that all the rainbows you ever saw were seen while the sun was shining. When the sun is behind you, and a shower is falling in front of you, the rays which pass through each drop are decomposed and the colors come out in such a direction that some of them enter your eye. Some drops send the red color to the eye: others in a different place send orange and others still send yellow; another set gives blue, another indigo, and finally another violet. And these seven colors are so arranged as to form the beautiful "bow of promise."

OPTICAL INSTRUMENTS.

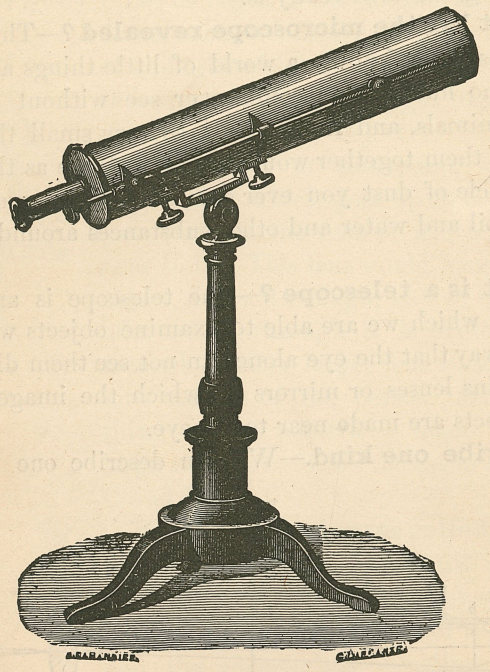
What does Fig. 58 represent?—By turning back to Fig. 58, we see that a convex lens when held between the eye and a little insect will help us to see a very large image instead of the little creature itself. Try it yourself by taking grandmother's spectacles, if you have no other lens, and hold one of the glasses just at the right place, which you can find by moving it back and forth between your eye and the page of the book. The letters will look much larger than they really are.

A double convex lens used in this way is called a *simple microscope.*

This little instrument, by making every little thing look larger than it is, becomes a very pleasant, and at the same time a very useful, instrument to every body. Most people use it for viewing fine engravings and in look-

telescope best by means of the foregoing diagram, Fig. 65. A large convex lens is in one end of a tube and a smaller one is at the other end. This small one is the *eye-glass*, and can be moved back and forth so as to be fixed at just the right distance from the other. The light from a distant body coming through the large lens forms an image at *a b*, and then a person looking through the eye-glass sees this image magnified at A′ B′.

Fig. 66.



The tube containing these glasses is mounted in some way to allow it to be pointed toward any object in the

heavens. The picture, Fig. 66, shows a small one. One of the largest of this kind of telescope in the world is at Harvard College. Its object-glass is about eighteen inches in diameter.

What has the telescope revealed?—The telescope has made known a great many things about the sun and moon and stars. It has shown that the moon is covered with mountains and valleys; and that the sun has immense black spots on its surface that looks to us so bright. It shows that there are hosts of stars in the sky, which could never have been seen without its help, some of them being so far away that light, travelling fast enough to go around the world about seven times a second, would need many hundreds of years to come from them to us.

Received here Nov. 25, 1891.

HEAT.

What is the chief source of heat?—From the sun more heat is received than from all other sources together. It is more than 90,000,000 of miles from the earth, and yet there comes out through that vast distance a constant flood of heat which, if withdrawn for a single year, would leave the whole earth in a degree of cold which even the Arctic regions never had.

What is a source of artificial heat?—Combustion is the chief source of artificial heat. Wood, coal, or other fuel burning in our stoves or furnaces warms our dwellings, cooks our food, and makes the steam by which our machinery is driven. Next to the sun, combustion is certainly the most important source of heat.

How is the heat in combustion produced?—If you shut the draught of an "air-tight" stove the fire will go out; or, if you put a lighted candle under the receiver of an air-pump, it will die away when the air is exhausted. We learn from such experiments that *no fuel can burn without air*. Unless air can pass over the hot fuel in the stove there can be no fire.

Now the air is made up of two parts which the chemist calls oxygen and nitrogen, and it is the *oxygen* of the air passing over the fuel which causes the combustion. The oxygen unites itself to the carbon and other materials of

which the fuel consists, and to this action the heat of the fire is due.

What is another source of heat?—Mechanical action, such as rubbing or pounding, will produce heat. Let the fingers be pressed down upon the table, and then smartly rubbed back and forth: the heat caused by this friction will be quickly felt. Or if a small cord or a thread is swiftly drawn through the hand which holds it tightly, the hand will be cruelly burned. If two pieces of wood are rubbed upon each other briskly enough they may be set on fire; in this way savage people are said to have kindled their fires: more civilized people now do it more easily by simply rubbing the end of a match.

Blows also produce heat, as any one may easily prove by pounding a bullet with a hammer, for he can soon make it too hot to be comfortably held in the hand.

Does heat pass from one body to another?—From every heated body rays of heat are continually going away. This is almost too familiar to need illustration, for the stove gives its warmth to all other objects in the room, and a red-hot cannon-ball will part with its heat so rapidly as to very soon get dark and finally cold.

But there is this curious fact to add to what has just been said: no body is at any time so cold that it is not giving off heat to every other around it. Heat is constantly passing away from every body, no matter how cold it may already be, and what is given off by one is being received by others in its neighborhood, so that it is true that even a block of ice is giving heat to a red-hot stove, if placed in its vicinity.

Then why do hot bodies grow colder?—Now if the ice and the stove in this illustration should each give

off just as much heat as it gets from the other back again, the ice would not melt nor the stove grow cold. But the hot stove is giving off much more than it gets, and on this account it becomes gradually colder if the fire is not kept up, while, at the same time, the ice gets much more than it gives, and is of course melted by it.

A body gets warmer only when it is getting heat from others faster than it is giving heat to them: it gets colder only when it gives heat faster than it gets it.

How does heat get from one body to another?—Heat travels outward from a hot body in waves something like the motion of water-waves when a pebble is thrown into a pond or lake. As the pebble puts the water in motion, so the hot body gives motion to the substance which fills the space around it; and as the waves of water spread outward in all directions from the pebble, so the waves of heat spread in all directions from their source. These waves of heat warm every body against which they strike.

With what velocity do these waves travel?—And they go from one body to another so very swiftly that one can not measure the small instant of time they take to pass through any common distance. They start from a hot stove and at the same instant they seem to strike the face of a person in the most distant corner of the room. Indeed, their velocity is so great that they would be able to go quite around the world as many as seven times in a single second! The velocity of heat is like that of light: together they come to us from the sun, a distance of about 93,000,000 miles, in 8 minutes and 18 seconds. This would be at the rate of about 186,000 miles a second.

What name is given to heat sent off by bodies in this way?—The heat which travels in this way is called *radiant heat.* Its peculiarities are, when briefly stated, *first*, it goes in straight lines; *second*, it goes in all possible directions from its source; and *third*, it moves with very great velocity.

This mode of transferring heat from place to place is called *radiation.*

Is there another mode?—Heat does not always travel in this way. If you take one of grandmother's knitting needles and hold one end of it in a lamp-flame you will feel the other very soon getting warm. The heat enters the metal at one end and travels, step by step, from one particle to another until at length it reaches the fingers. In this way it is carried from one part of a body to another, or it may be from one body to another, if they touch each other. This mode of transferring heat is called *conduction.*

Do all solids conduct heat alike?—If we take two wires of equal size and length, one being of copper and the other of iron, and place one end of each in a flame, we shall find that the heat travels through the copper to the other end quicker than through the iron. Copper conducts heat better than iron does. A rod of glass may be melted within an inch of the fingers that hold it without burning them, and a splinter of wood may be held in the same way while it burns to ashes.

We thus learn that each solid has a rate of its own at which it may conduct heat. Liquids scarcely conduct it at all, and gases in a degree still less.

Bodies that conduct heat freely are called good conductors, but those that do not are called poor conductors or non-conductors.

Are liquids and gases conductors of heat?—Water is so very poor a conductor of heat that if you put

ice at the bottom of a glass vessel and then apply heat to the water above it, Fig. 67, you may make the water boil

Fig. 67.

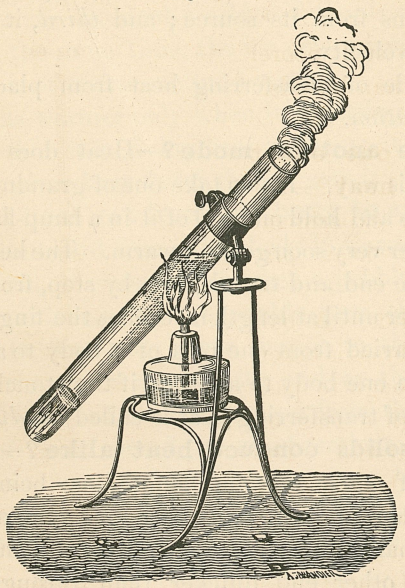
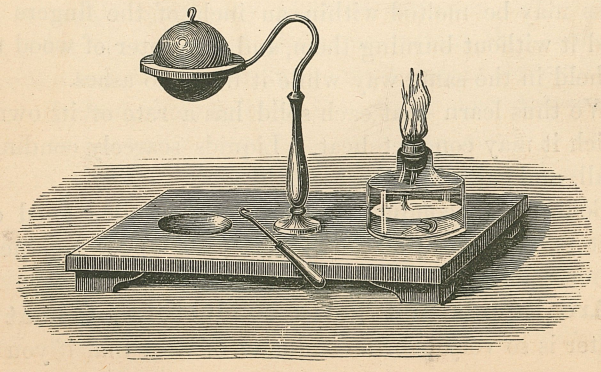


Fig. 68.



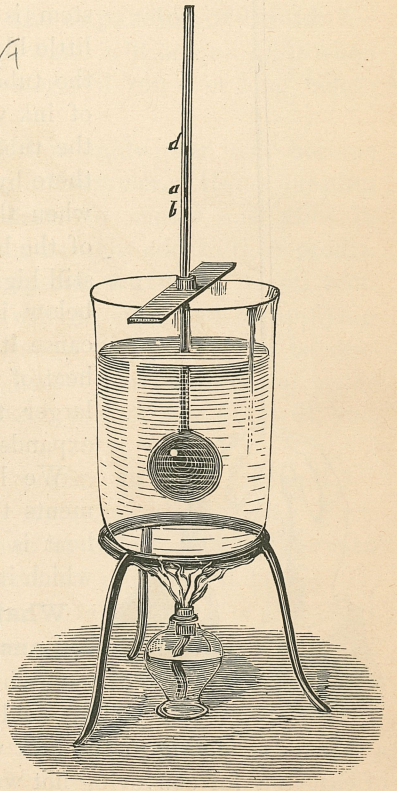
without melting the ice; the heat will not travel downward through the water to the ice. Other liquids, except mercury, are like water in being very poor conductors of heat.

Gases are still poorer conductors than liquids.

What is one effect caused by heat?—Let us learn by experiment what effect heat produces:

1st. In solids. A ball of iron or of brass is taken just large enough to pass easily through a ring of the same material. The ball is then heated by a lamp, after which it will be too large to go through the ring. It will rest upon the ring (Fig. 68) until it gets cold again, when it once more passes easily as at first. We see that heat makes this ball larger. And it has the same effect upon other solids.

Fig. 69.

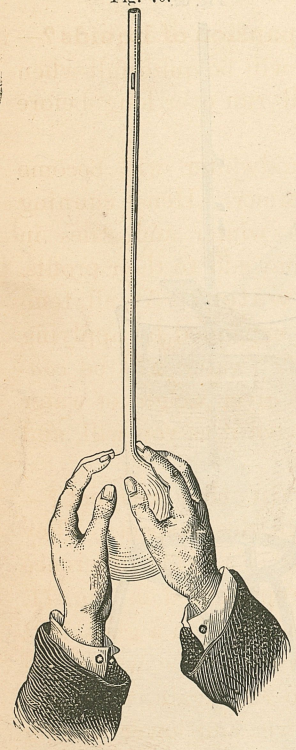


2d. Liquids. A glass bulb with a long open stem is used. The bulb is filled with water and the stem partly filled, after which, if the bulb is plunged into hot water (Fig. 69), the water in the stem will be seen slowly rising,

until perhaps it will run over the top. The water grows larger as it gets warmer. We see that heat expands this liquid: it does the same thing for others.

3d. Gases. Fig. 70 shows an experiment with air. The glass bulb with its long open stem is used for this also. The little black spot near the end of the tube represents a little drop of ink which has been put into the tube and which will be held there by the walls of glass. Now when the warm hands take hold of the bulb the drop will run up still higher in the tube. The air below it pushes the ink up because it wants more room. The heat of the hand makes the air larger than it was. Heat also expands all other gases.

Fig. 70.



We learn from these experiments that the general effect of heat is to expand all bodies to which it is applied.

What facts illustrate the expansion of solids?—An iron gate which opens and shuts easily in cold weather, will stick, in a warm day, owing to the heat which expands it. Pipes of cast-iron for conveying hot water are longer when full than when empty. It is said that an ignorant man once tried to warm a large manufactory by steam. He laid one large iron pipe from the boiler to the farther end of the building, and then passed branches from this through

holes into the several rooms. The very first time he filled the pipes with steam, the expansion of the main pipe tore it away from all its branches!

The rails of a railroad-track are longer in summer than in winter.

What facts illustrate the expansion of liquids?—A kettle nearly full of cold water will be quite full when the water is heated: the water will run over long before it boils.

Twenty gallons of alcohol in midwinter will become about twenty-one gallons in midsummer. Hence cunning dealers try to make purchases in winter and sales in summer, that the heat of summer may add to their profits.

Does heat always expand water?—At all temperatures above 39° water will be expanded by applying *heat*, but at temperatures below 39° water will be *contracted* by applying heat. At 39° a given weight of water is as small as it can be; heat it or cool it as you will, and it will be expanded.

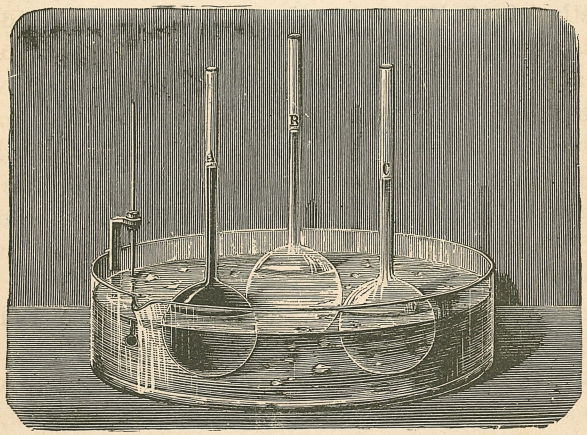
Are all liquids like water in this respect?—Other liquids are not like water in this respect. They have their smallest volumes at 32° F. This difference may be shown by an experiment represented in Fig. 71. Let water, alcohol and oil, each contained in a glass butt and stun, be placed in ice-cold water. The water will fall in the stun and then begin to rise again, while the other liquids will continue to go lower and lower as long as their temperature falls.

Suppose the water cooled to 32°?—At 32° the *water freezes*. The expansion at this moment is greater than at any moment before, so that the *ice* is *larger* than the *water* from which it is made.

On this account pitchers and water-pipes are often broken by the water freezing in them.

Ice being larger must also be *lighter* than the water from which it is made. Were it not for this fact our ponds and rivers would never be covered with a blanket of

Fig. 71.



ice as now they are in the winter. The ice, instead, would sink to the bottom as fast as formed. As it now is, the ice stays on top and keeps the water from freezing to any great depth; but if it should sink, it would go on forming until the whole body of water would become ice from bottom to top, and then the atmosphere would get colder and colder, until neither plants nor animals could live at all.

What facts illustrate the expansion of air?—The snapping of wood in the fire is caused by the expansion of air. The air in the pores of the wood, suddenly heated, expands and bursts the wood with a sharp report.

The first balloons that were made were filled with hot air, and they went up toward and even above the clouds,

because the air they contained was expanded and made lighter than the cold air—so light that it could rise and carry the balloon up with it. Only toy-balloons are now filled with hot air; those by which men are carried to the clouds are filled with common illuminating gas, or sometimes with hydrogen.

Which are most expanded by heat, solids, liquids, or gases?—A little addition of heat expands a gas very much; the same applied to a liquid would cause an increase in size difficult to see, and if it were applied to a solid, would not change its size enough to be noticed at all.

Do all solids and liquids expand equally?—Instead of all solids expanding equally, each one has a certain rate of its own. Brass for example, will expand faster than iron. Each liquid also has a rate of its own.

Do all gases expand equally?—Gases all expand alike by heat. Air, oxygen, and all other gases, heated alike, will expand equally.

What is a second effect of heat?—If iron is heated it will go on expanding long after it has become red-hot, until finally it *melts*. The solid is then changed into a liquid; this is a second effect of heat. It is called *liquefaction*.

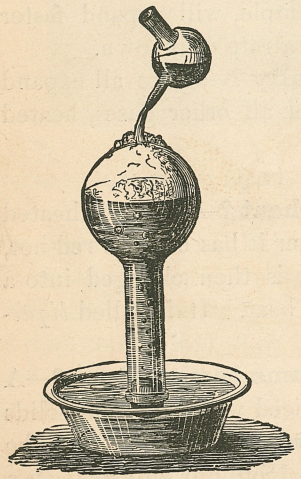
Do all solids melt at the same temperature?—A few examples which all have noticed will show that solids melt at very different temperatures. The warmth of the hand will melt ice, but not wax. Sulphur will melt on a hot stove; it needs a temperature of 230°, but iron does not melt until it is heated to about 3,000°. Each substance has a certain temperature at which it melts. This temperature is called the *melting-point*.

What is a third effect of heat?—If water is heated it will go on expanding until its temperature is 212°; at this temperature it *boils*. The liquid is then changed into a gas; this is a third effect of heat. It is called *vaporization*.

Do all liquids boil at the same temperature?—Water boils in an open iron vessel at the temperature of 212°, but alcohol will boil at 173°, and ether only needs to be heated to 95°. These illustrations show that each liquid has its own degree of heat at which it boils: this temperature is called the *boiling-point*.

Describe the experiment in which, by cooling the vessel, water is made to boil.—A very curious experiment is represented in Fig. 72. In the first place a glass bulb with long open stem is partly filled with water. This water is then boiled for some time until the steam has driven all the air out of the vessel. While the water is still boiling, the stem is tightly corked and the heat taken away at the same moment. All this is done to get rid of the air and leave nothing but water and steam in the vessel. The bulb is then turned upward as in the picture. After this *pour cold water* upon the bulb, and *the water inside will boil* vigorously. Stop pouring cold water and the boiling will cease, but as often as the cold is applied the boiling will begin. This may be kept up until the vessel is cold enough to be held in the hand without inconvenience.

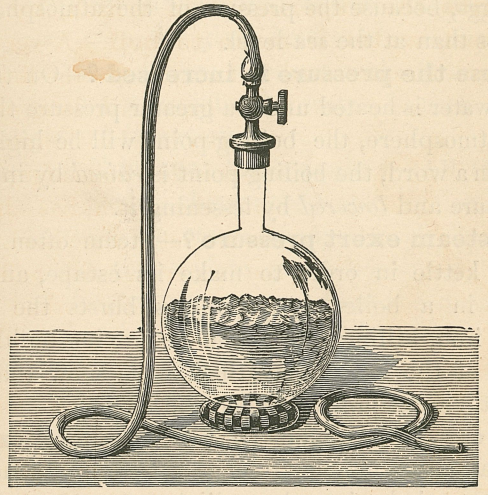
Fig. 72.



What does the cold water do?—Now all that the cold water does is to cool the steam that is in the bulb and condense it into water. By this means the *pressure* of the steam is taken off from the water inside.

Describe another experiment in which water is made to boil without fire.—The pressure may be taken from the surface of the water in another way. The water is put into a flask, to the top of which is fastened a long tube. This arrangement is shown in Fig. 73. The

Fig. 73.



water is then heated until it begins to boil. The flask is then taken from the fire and its tube is fastened to the plate of the air-pump. On working the pump, the air and steam are taken from the flask, and the water, which by this time is much below 212°, begins to boil violently.

What do these experiments teach?—We learn from these experiments that by taking pressure away from

the surface of water, boiling will go on at a lower temperature.

In the open air water boils at 212°, but the pressure of the atmosphere is 15 lbs. upon each square inch of surface. If it were not for this pressure water would boil at a temperature much lower than 212°, indeed at a temperature not much above that of a hot summer day.

Water boils at a low temperature on top of high mountains. In fact, at places very high above the level of the sea, boiling water is not hot enough to cook meat, or even to boil eggs, because the pressure of the atmosphere is so much less than at the sea-level.

Suppose the pressure is increased?—On the other hand, if water is heated under a greater pressure than that of the atmosphere, the boiling-point will be higher than 212°. In a word, the boiling-point is *raised* by increasing the pressure and *lowered* by lessening it.

Does steam exert pressure?—Steam often lifts the lid of a kettle in order to make its escape, and when confined in a boiler, it sometimes bursts the stoutest bands of iron, killing people and destroying buildings by the force of the explosion. Such facts show that steam can exert a great pressure when confined.

How can it be used to move machinery?—If there is a piston moving freely inside of a cylinder, and then if steam is let into the cylinder, first at one end and then at the other, its expansive force or pressure will knock the piston back and forth from one end to the other with great rapidity and power. The piston may move a crank which turns a wheel, and then by bands or cogs this wheel may turn other wheels. In this way steam is made to move machinery. This is the principle of the *steam-engine*, by which ships are driven over the

sea and railroad trains across the continent, and by which so much of all the machinery in the world is moved.

Can water be heated above 212°?—If water is slowly heated its temperature will rise until the liquid boils at 212°: after that the water grows no hotter. The fire may be quickened and the boiling will be more violent, but the water will not become any hotter. This is always true when the water is heated in open vessels such as are generally used.

What becomes of the heat added to the boiling water?—Now the fire gives heat to the boiling water all the time, but, as we see, does not make it any hotter. All the heat that goes into the water is then used *in changing the water into steam.*

Can we get this heat back again?—All this heat which has been used to change the water into steam, will be given up when the steam changes back into water. This is the reason that a plate grows hot so very quickly when held in the steam that issues from the spout of the tea-kettle.

Is this principle ever applied?—Buildings are sometimes warmed by steam. From a large steam-boiler cast-iron pipes are laid to the many rooms to be warmed, and the steam is forced through their entire length. The steam is condensed in going through the cold pipes, and gives up to them the heat which it took from the fire. They very soon become very warm, and warm the air which is in contact with them.

Do we know the temperature of bodies by feeling them?—Let us take three vessels of water, one almost as cold as ice, another just warmer than the hand, and a

third as hot as the hand can bear. Let one hand be held in the first vessel of cold water and the other in the vessel of hot water for a while, and then let both be plunged into the vessel of warm water. It will be found that to one hand the water is cold, to the other it is hot, at the same time. Of course, by the feeling we could not tell whether it is really hot or cold.

Give another example.—An oil-cloth and a carpet, where they lie together upon the floor, are of the same temperature, but the oil-cloth will feel cold and the carpet warm to the hand at the same time.

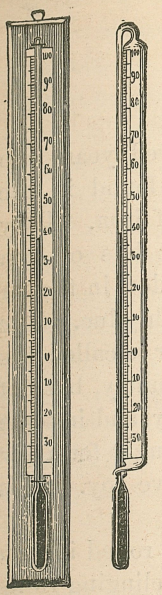
The reason of this is that the oil-cloth is a better conductor of heat than the carpet, and takes the heat of the hand away faster, so that the hand grows cold quicker when upon it.

By what instrument can we find the temperature of bodies?—The instruments by which to measure temperature are called *thermometers*. The common thermometer contains mercury, which expands when heated, and contracts when cooled, and by these changes of volume shows the temperature.

Describe the common thermometer.—The thermometer is very common, and a single look at it would be better than any description of it can be. However, it may be described as a glass tube, with a bulb at one end, while the other end is shut air-tight, containing mercury which fills the bulb and part of the stem, and having a scale behind the stem to show the height of the fluid. Fig. 74 shows two forms of this instrument.

How is it used?—By putting the bulb into water or any other substance the height of the mercury in the stem will show how hot it is. Put the bulb in water, for instance, and if the mercury rises in the stem up to the

Fig. 74.



place marked 90 on the scale, then the temperature of the water is 90°.

How is Fahrenheit's thermometer graduated?—The place where the mercury stands when the bulb is immersed in boiling water is marked 212° on the scale; where the mercury stands when the bulb is immersed in freezing water is marked 32°: the space between these is divided into 180 equal parts, called degrees, and divisions of the same size are marked off on the scale both above and below these points.

How is the centigrade thermometer graduated?—In the centigrade thermometer, the place where the mercury stands when the bulb is placed in boiling water is marked 100°; where it stands when the bulb is in freezing water is called 0°, and the distance between is divided into 100 equal parts or degrees.

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Examined to here December 11, 1891. G.M.B.

MAGNETISM.

What is a loadstone?—Several hundred years ago pieces of a certain kind of iron ore were found in the earth which had the power to attract bits of iron. They would lift needles or small nails or other bits of iron which they touched, and hold them suspended in the air as if they were cemented to the stone with glue. The ore of iron which has this wonderful power is called the *loadstone*. It is found sometimes in this country, but not in such abundance as in Sweden and Norway, and in some parts of Asia. A good specimen may be bought for a few cents, and it is an interesting and instructive toy. It is often called the *natural magnet*.

What is a magnet?—If a loadstone is rolled in iron filings it will attract them and hold them clinging to its surface, but when rolled in filings of brass or copper not one of these will it pick up. It has a curious preference for iron. Any body that will attract iron in preference to other metals is called a *magnet*.

What are artificial magnets?—A bar of steel may be made a magnet by simply rubbing it upon the loadstone. In this way the blade of a penknife may be given the power to pick up bits of iron, such as small needles, tacks, or iron filings. One blade can get this power also from another which has been already made magnetic; and what is a little singular, perhaps, is that the one that gives

this power to another is none the weaker for it; it is even stronger than before. All such pieces of steel are magnets.

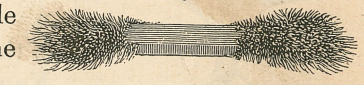
Iron also may be made magnetic, but it will not stay so unless it be first hardened more than usual.

In what two shapes are magnets made?—Artificial magnets are made in two forms. They are generally either a straight bar of steel or else a bar bent into the form of a horse-shoe. The first is called the *bar magnet*, and the second is called the *horse-shoe* magnet.

What is an armature?—A horse-shoe magnet generally has with it a bar of iron to reach across from one end of the magnet to the other. Such a bar is called the *armature*.

In what part of a magnet is the attraction strongest?—By rolling a bar magnet in a bed of iron filings and then lifting it, the filings may be seen clinging to the ends of the bar in curious tufts (Fig. 75), while along the middle few or none will be found.

Fig. 75.



This experiment shows the power of the magnet to be much greater at the ends than elsewhere. The ends of the magnet, or the points at which the force is strongest, are called the *poles*.

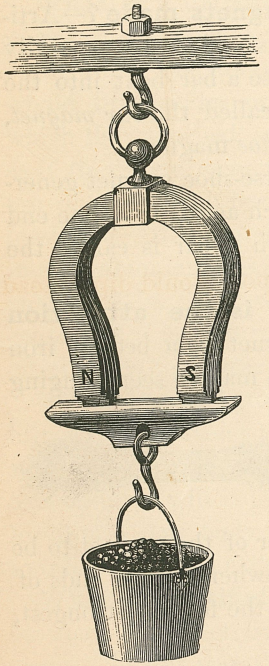
Fig. 76 represents a horse-shoe magnet with an armature across the poles holding up a heavy weight.

What is the magnetic needle?—A slender bar magnet balanced upon a pivot (Fig. 77) is called a *magnetic needle*.

Left to itself, such a needle will always be found pointing toward the north and south. It will not rest in any other position. If you push it out of this direction it will

swing back again the moment you let go of it, and after vibrating from one side to the other for a time, it will at last come to rest again with *the same end* to the north as before.

Fig. 76.



The end that points toward the north is called the *north pole:* the other end is called the *south pole.*

What use is made of the magnetic needle? — What is called the mariner's compass is a magnetic needle placed over a dial on which are marked north, south, east, west, and many other directions, or as they are called, "points of the compass." This little instrument is placed where it will be every moment in view of the man who guides the ship, and tells him every moment in what direction the ship is going.

No matter how dark the night or how rough the sea may be, the faithful needle, pointing always so nearly north and south, guides the storm-tossed seaman safely to his port.

What is a dipping needle?—If a magnetic needle is hung in a way to let its poles move up and down it will not rest in a horizontal position. The picture (Fig. 78) shows what direction it will take: the north pole will be lower than the other. A needle fixed in this way is called a *dipping needle.*

Is the dip of the needle everywhere alike?—The

dip of the needle is not the same in all places on the earth. In the most northern regions the needle is most oblique, that is to say, the dip is greatest. Just at the north pole the needle would point its north pole downward to the ground. As the needle is carried farther to the south the north pole rises until when at the equator the needle would be horizontal, or have no dip at all, and then when carried farther into the southern hemisphere the south pole would dip instead of the north pole.

Fig. 77.

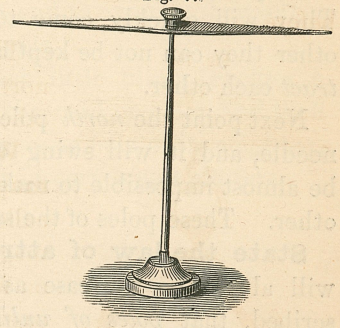
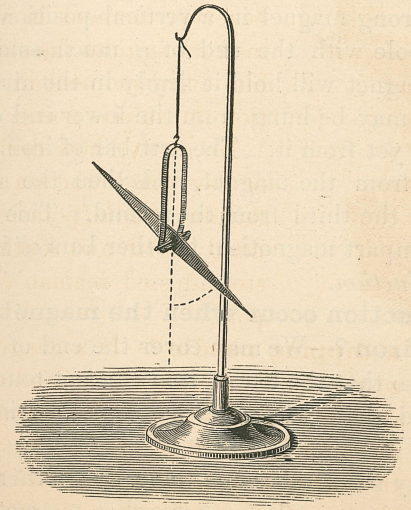


Fig. 78



How will one magnet act upon another?

Let one magnet be brought near to another; suppose, for instance, that you hold one in the hand and point its *north* pole toward the *south* pole of the magnetic needle. They will quickly come together: if in reach of each other they can not be kept apart. These unlike poles *attract* each other.

Next point the *north* pole toward the *north* pole of the needle, and it will swing quickly away, so that it will be almost impossible to make the two magnets touch each other. These poles of the same name *repel* each other.

State the law of attraction and repulsion?—It will always be the case as in the experiments just described, that *poles of unlike names attract each other, while poles of the same name repel each other.*

Describe the experiment to illustrate induction.—Hold a strong magnet in a vertical position and touch the lower pole with the end of a much smaller bar of iron: the magnet will hold it firmly in the air. Another smaller bar may be hung from the lower end of the first, and another yet from it. The first bar of iron receives its magnetism from the magnet, and then the second from the first and the third from the second. This power of a magnet to impart magnetism to other bars of iron or steel is called *induction.*

Will induction occur when the magnet does not touch the iron?—We may cover the end of the magnet with paper so that the bar of iron can not touch the pole, and yet find that it becomes a magnet by induction as before.

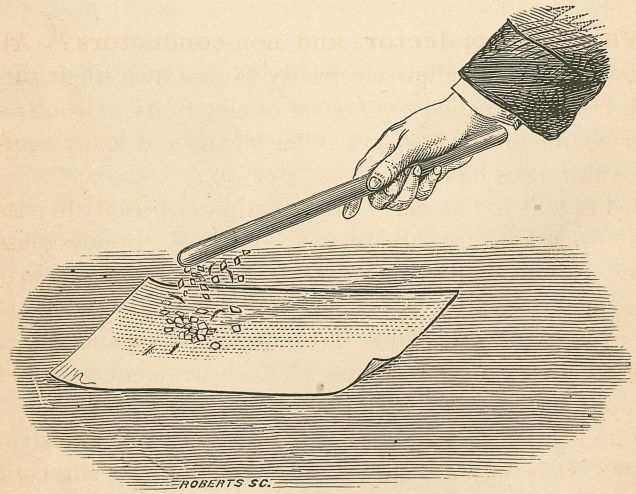
Or we may show this same thing by another and more curious experiment. Let a horse-shoe magnet be placed poles upward, and lay across its ends a piece of stiff cardboard or a piece of glass. Sprinkle iron filings upon the cardboard and at the same time gently tap it with the finger. The filings will then be seen to collect in clusters around the poles of the magnet and to arrange themselves in strange curves from pole to pole.

Now in this experiment each little filing becomes a magnet by induction through the card or glass, and then each pole of one attracts the opposite pole of its neighbor, so that they cling to each other in curves and clusters.

ELECTRICITY BY FRICTION.

Describe the experiment with the glass rod.—Fig. 79 shows the results of an easy and amusing experiment. A glass rod, or perhaps a stick of sealing-wax, must be rubbed briskly with a flannel cloth for a few

Fig. 79.



moments, and then held near to pieces of some light substance, such as bits of cotton or balls of pith taken from the elder-bush or corn-stalk. These light bodies will quickly jump upward against the rod, and then, as if disappointed with their visit, as quickly jump away again.

What does this experiment show?—We see by this experiment that rubbing glass with flannel gives to the glass a power which it did not have before—the power to attract and to repel light substances.

What is this power called?—This new power aroused in the glass is called *electricity*. In this case the electricity is produced by *friction*.

Does friction always produce electricity?—Whenever substances are rubbed together electricity is evolved. And yet if an iron rod is used in place of the glass in the experiment (Fig. 79), the pith balls will not stir from the table, because the electricity flies along the surface of the iron and away through the hand as fast as it is produced.

What are conductors and non-conductors?—All bodies which will allow electricity to pass over their surfaces freely are called *conductors* of electricity. Iron is a good conductor, and so are other metals and many common substances besides.

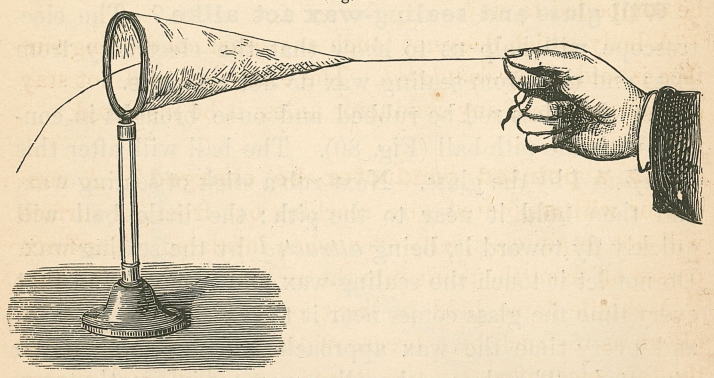
Bodies which, like glass, will not allow electricity to pass freely over them are called *non-conductors*. Besides glass many other common substances are non-conductors. Air is one of the most perfect of them all. And among others it is well to mention India-rubber, sealing-wax, and silk.

What is an electroscope?—An instrument to detect the presence of electricity in any body is called an *electroscope*. Fig. 80 will give a good idea of one of these instruments. It is only a little ball of pith hung by a silk cord from the end of a standard.

The glass rod, after being rubbed with the flannel cloth, will show its electricity by attracting the pith-ball. On coming in contact with the glass the pith itself becomes electrified, and then jumps away from the glass.

Show that electricity is only on the outside surface of a body.—Fig. 81 shows a curious experiment which teaches us where the electricity of a body is to be

Fig. 81.



found. A sack made of muslin and in the shape of a cone is fastened to a metallic ring upon a standard. The sack is to be held out by a long silk cord. When the ring is brought in contact with any body already charged with electricity, the force will spread into the ring and from it into the sack. On examining the sack its *outside* surface will show the presence of electricity, but its *inside* surface will not. Now by taking hold of the other end of the cord the sack may be turned inside out; and, on examining again, the electricity is found to be on what is now the outside, while not a trace of it can be found upon the inside. No matter how often nor how quickly the sack is turned inside-out, the electricity will always be found on the *outside*.

Can a conductor be charged with electricity?—Since electricity will pass freely over the surface of any

conductor, it would at first seem to be impossible to make it remain, or, in other words, to charge the conductor. But let the conductor be placed upon a glass support, and the electricity will have no means of escape, so that it will be compelled to stay.

A body which does not touch any other conducting surface is said to be *insulated*. The electricity can not stay on the surface of any conductor unless it be insulated.

Can a pointed conductor be charged?—A conductor with a pointed wire reaching out from its surface will not retain electricity even when insulated. The force passes off from the point into the air, and seems to be lost.

A candle-flame held in front of such a point will be blown as if struck by a breeze of air, and indeed it is, for the air electrified by the point is repelled and moves away: it is this current of air that wafts the flame.

Suppose a pointed conductor brought near to an electrified body.—If we put the pointed end of a wire near to any body which is electrified it will draw the electricity away without touching it. To point the finger at the prime conductor of an electrical machine will be almost enough to keep the conductor from being charged: and an open penknife held in the hand and pointed at the conductor will be found quite enough to draw away the electricity as fast as it is evolved.

For what purpose are pointed conductors used?—Lightning-rods are *pointed conductors*, which are used to protect buildings from being struck by lightning.

Lightning is nothing more than the *light* caused by electricity in the air or clouds, and thunder is only the *noise* that is made by the electricity when it passes from one cloud to another or to the earth.

When a cloud full of electricity floats along over a house the electricity sometimes leaps into the building and tears it to pieces, or perhaps sets it on fire; but if the house has a good lightning-rod reaching above the roof, the point of the rod will take the electricity out of the cloud silently and gradually, and in this way the disaster may be prevented.

Who first took lightning from the clouds?—Dr. Franklin first drew electricity from the clouds in such a way as to be able to examine it, and prove that lightning is nothing but electricity.

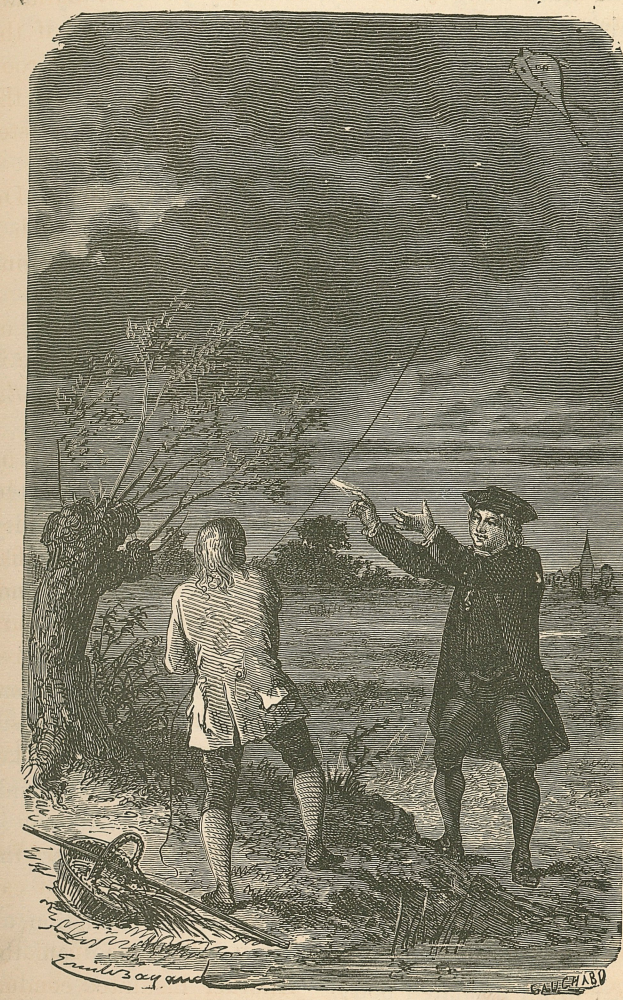
How did he do it?—This discovery of the nature of lightning was one of the most important ever made in the science, and yet, Dr. Franklin made it simply by *flying a kite in a thunder-shower* (Fig. 82).

He made his kite of silk instead of paper, and sent it up with a hempen cord ending in a piece of silk cord, by which the kite was held. It is said that he fastened a door-key to the lower end of the hempen cord, and that after his kite had been for some time sailing among the clouds he touched this key with his knuckle and drew a spark of electricity from it. The electricity in the cloud entered the kite, and came down the hempen string to the key, but could not go any farther because the silk cord was a non-conductor. When the doctor presented his hand the electricity in the key leaped into his knuckle.

Can electricity act through non-conductors?—The following experiment will show that electricity can and will act through non-conductors.

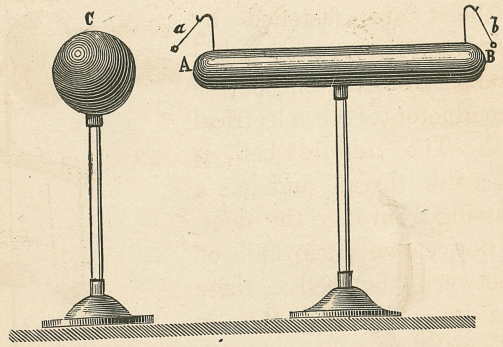
We will suppose the ball C (Fig. 83) to be insulated and charged with electricity. Another insulated conductor, AB, is slowly moved toward the ball, and when the

Fig. 82.



end of it is still at some distance, the pith-balls, which have all the time hung vertically, suddenly jump away and remain as shown in the picture.

Fig. 83.



The action of the pith-balls shows that the insulated conductor AB is electrified, and we see that the electricity of the ball C must have acted through the air. It would have the same effect through glass or other non-conductors.

What is this action called?—This action of a charged body through non-conductors is called *induction*.

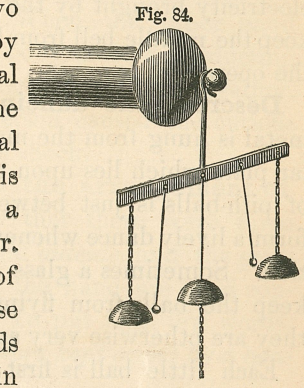
What is its effect?—It will be found that the insulated body AB is not electrified all over its surface alike. *Both kinds of electricity are found upon it.* The ends are most powerfully electrified, and *the two ends are in opposite conditions.* The end B, most distant, has the same kind of electricity as the charged ball C.

Such will always prove to be the case. Induction always causes *both kinds* of electricity to appear on the surface of an insulated body.

How do we describe this condition of an insulated body?—When both kinds of electricity are developed on the surface of a body, it is said to be *polarized*.

Describe the electrical bells.—Fig. 84 shows a chime of bells, which are to be rung by electricity. Notice how they are arranged. The two outside bells are fastened by metal chains to a rod of metal which hangs from the end of the prime conductor of an electrical machine. The middle bell is hung by a silk thread and has a chain passing from it to the floor. Finally, notice two little balls of metal between the bells: these balls are hung by silk threads also. When the machine is in operation, these little balls will fly back and forth and ring the bells loudly.

Fig. 84.



Explain this experiment.—The electricity from the machine passes down the chains into the outside bells, but it can not get into the middle bell nor into the little balls, because their silk cords are not conductors. Now when one outside bell is charged, its electricity will act through the air upon the little ball and *polarize* it, and the electricity on that side of the ball nearest the bell is the other kind from that in the bell itself. Then the two unlike kinds attract each other, and this is what brings the ball to strike the bell.

But when the ball touches the bell it takes electricity from it, and then the two, having the same kind of electricity, repel each other. This is what throws the little ball against the middle bell. But when it touches the middle bell it gives away its electricity and is ready to be

polarized over again. It is first *polarized*, then *attracted*, then *repelled* over and over again, perhaps fifty times while we are giving the explanation once.

The chain from the middle bell is to conduct away the electricity brought by the little balls. This is needed to keep the middle bell from becoming charged, and stopping the operation.

Describe the dancing pith-balls.—If a plate of metal is hung from the machine just above another similar plate which lies upon the table, and then if a handful of pith-balls is just between the two, these balls will perform a lively dance whenever the machine is put in operation. Sometimes a glass shade is put over the disks to keep the balls from flying away from between them, as they are otherwise very sure to do.

Each little ball is first polarized by the electricity in the upper plate, and then attracted and afterward repelled.

What do these experiments illustrate?—These experiments illustrate the fact that no light body is ever *attracted* until after it is *polarized* by the charged body toward which it flies.

Describe the charged goblet of water.—A long time ago a gentleman in France was experimenting with electricity to see how it would affect water. A chain from the conductor of his machine hung down into a goblet of the liquid, but it seemed to produce no effect, and he was about to take it away. He seized the goblet in one hand and took hold of the chain with the other. The moment that his fingers touched the chain, he received a shock which convulsed his hands and gave him such a fright that he did not quite get over it in two days.

Explain this experiment.—The water in the goblet was charged with electricity from the machine, and when the hand was placed around the outside, it and the glass were *polarized*, so that the outside and inside of the goblet were in opposite conditions. When the other hand touched the chain the arms and body made a conducting road through which the two electricities could get together, and their action through the person caused the curious and unexpected feeling called the shock.

What should we notice in the arrangement of the goblet?—Now we notice that there were three things—the water *inside*, the hand *outside*, and the glass *between*, and that the water and the hand are good conductors, while the glass is not. To put it in few words, we see that *there were two conductors kept apart by a non-conductor.*

Describe the Leyden jar.—Any two conducting substances kept apart by glass will answer just as well, or indeed very much better than the water and the hand. Tinfoil is pasted over the surfaces of a glass jar, both inside and outside, to within a few inches of the top, and then the jar is covered with a cover made of hard wood, through which passes a brass rod. There is a ball on the top of this rod, and a chain at its lower end that reaches down to the bottom of the jar.

How may the jar be charged?—Let the jar be held in the hand with its knob very near to the conductor of the machine. Sparks of electricity will fly into the knob; in a dark room they look like little flashes of lightning. After a while, when the sparks are feeble, the jar is said to be *charged.*

How may it be discharged?—Should a person accidentally touch the knob of the charged jar with one hand

and the outside tinfoil with the other, he would feel a shock which would startle and perhaps injure him. His body is a good conductor, and the shock is due to the discharge of the jar through it. A discharge will always occur when any conductor reaches from the knob to the outside coating of the jar. A bent wire with a glass handle is generally used for the purpose.

ELECTRICITY BY CHEMICAL ACTION.

What is meant by chemical action?—When a piece of paper burns it ceases to be paper, as every one knows, and changes into smoke and ashes. The *nature* of the substance is changed during the action. Now this shows what we mean by chemical action. It is an action by which the *nature of a substance is changed.*

We will mention another case. Put some bits of zinc into a goblet and pour upon them some weak sulphuric acid. The fluid will soon begin to boil violently, and bubbles of gas will be given off, so that often, if a lighted match is held near, the gas will take fire. This will give the curious appearance of *water on fire.* After a while the action will stop, but not until much and perhaps all the zinc has been used up.

Why is this action a chemical action?—In this case both the zinc and the acid are changed into other substances, and on this account the action is called a chemical action.

Will it produce electricity?—Now let a strip of zinc and another of copper be placed side by side in a glass vessel nearly full of weak sulphuric acid, but do not let them touch each other. Have a wire fastened to the upper end of each metal. It will be found that whenever these wires come together electricity will act through

them. This electricity is due to the chemical action going on in the vessel.

What is this apparatus called?—This simple apparatus is called a *Voltaic circuit.* The electricity it gives is often called *Galvanism* and often *Voltaic electricity.* These names were given in honor of Galvani, who first studied this force, and of Volta, who also made it a study, and found out many new things about it.

What are the poles of the circuit?—The ends of the wires are commonly called the poles of the circuit. One is called the *positive* pole and the other is called the *negative* pole.

When the poles are in contact, or when there is any conductor which joins them together, the circuit is said to be *closed*, but when they are separated the circuit is said to be *open.*

What effects can this circuit produce?—The electric force in this simple circuit is very weak. It can make its presence known by a feeble spark seen in the dark at the moment when the wires are separated, but which can be seldom seen at all in daylight. It also causes bubbles of gas to rise alongside of the copper plate when the circuit is closed. And, what is more curious still is that it will turn a magnetic needle, when the wires are laid lengthwise of the needle, *without touching it.* You will learn more of these effects at some future time.

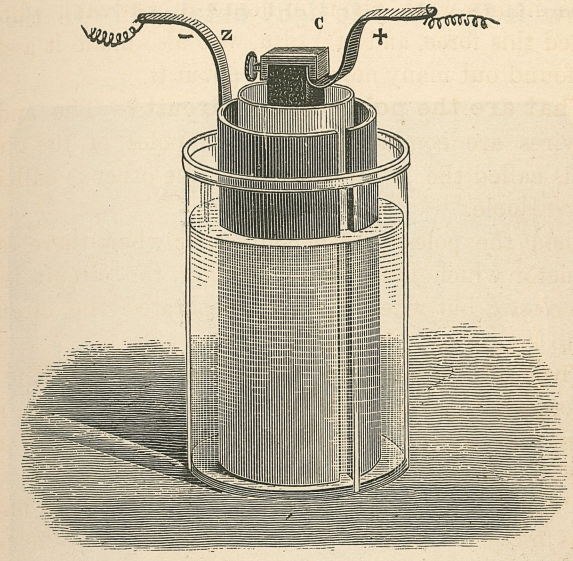
Can greater effects be obtained?—Very much greater effects can be obtained by using a different apparatus. One of the best kinds is the *Bunsen's battery.*

The picture Fig. 85 will help us to understand how the Bunsen's battery is arranged. It consists of—

1. A glass or earthenware vessel, containing
2. Dilute sulphuric acid. In this stands

3. A hollow cylinder of zinc. Inside of this is
4. A porous earthen cup, filled with
5. Strong nitric acid. And finally in this
6. A rod or block of carbon is immersed.

Fig. 85.



One wire or metallic bar goes from the carbon; this is the positive pole: another goes from the zinc, and this is the negative pole.

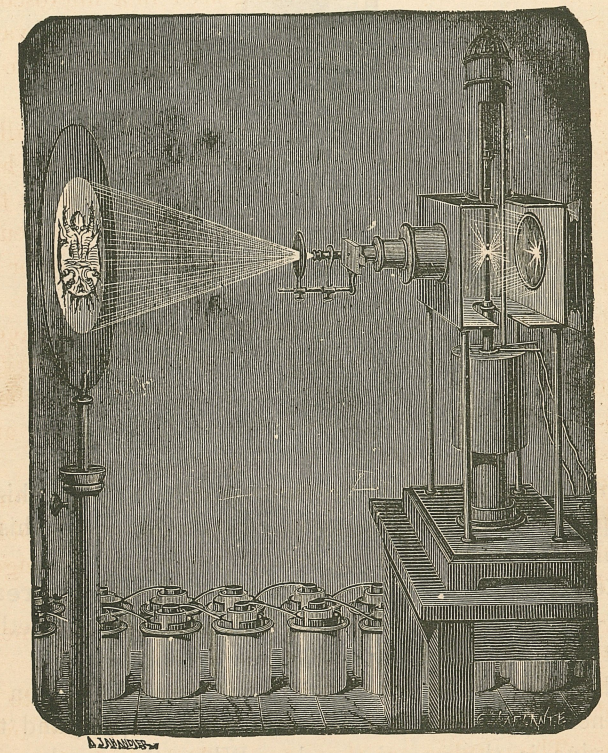
How may the power of the battery be increased?—By joining several of these single batteries together electricity of almost any power may be obtained.

The zinc of each cell may be joined to the carbon of the next. The first carbon is the positive pole, and the last zinc is the negative pole. When these poles are joined together a powerful electric force is obtained, by which most wonderful effects are caused.

Describe the electric heat.—If a fine iron wire is stretched between the poles of a strong battery it will be quickly heated white hot, and actually burned up, even when several inches long. Copper, zinc, and other metals melt readily and are burned by electricity.

How is the electric light obtained?—In the pic-

Fig. 86.



ture, Fig. 86, the electric light is represented as in use. The battery, a very strong one of 50 or perhaps 100 cells,

stands upon the floor. The lamp stands upon the table. The light is obtained by having the poles tipped with charcoal and then drawing them a little way apart. It is of the most dazzling brightness. The light is not due to the *burning* of the charcoal, for it is as bright when made in a vacuum where the carbon cannot burn at all.

In the picture this light is being used in a microscope. It is made to pass through an insect and afterwards through convex lenses, which form a magnified image of the creature upon the screen.

"With this instrument it is possible to show the smallest objects magnified almost indefinitely. A human hair will appear as large as a broomstick; an ordinary flea will look the size of a sheep, and the smallest animalcules will be visible in all their beauty of form and color as clearly as if they were seen with the naked eye."

The electric light has been used also, sometimes, to enable workmen to labor at night. When it is necessary to accomplish a great work speedily, it may go on without stopping, the sun giving the workmen light by day and the electric light by night. See Fig. 87.

How may water be decomposed?—We need only put the poles of a strong battery into water and bubbles of gas will rapidly rise from both. The water is changed into *two gases*.

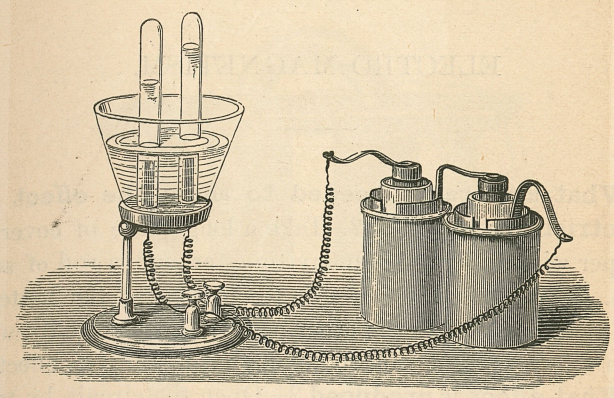
The picture, Fig. 88, will show us how the experiment is usually made.

We see that the wires from a battery go up into a vessel of water and that two tall tubes are placed over them. These tubes are there to catch the little bubbles of gas into which the water is changed. They were filled with water at the beginning of the experiment, but as the

Fig. 87.

bubbles rise they drive the water out. One tube is filling twice as fast as the other, you may notice.

Fig. 88.



What gases are these ?—One of these gases is *hydrogen*, the other is *oxygen*. The hydrogen is given off most rapidly.

The electricity in this case helps us to learn that water is made up of two very light and colorless gases, hydrogen and oxygen, and that it contains twice as much of the first as of the second.

A great many other substances may be decomposed by electricity.

ELECTRO-MAGNETISM.

What apparatus needed to show the effect of electricity upon iron?—Take a long piece of covered copper wire and wind it many times around a rod of soft iron. Fix one end of this wire to one pole of the battery and the other end to the other pole. The electricity will then act around the iron rod and we can study its effects.

What effect is produced?—Open the circuit by taking the wire away from one pole of the battery, and we may by trial find that the iron has no especial attraction for small bits of iron which are brought in contact with it; but close the circuit, and instantly the bits of iron will cling to the rod and be held by it as long as the electricity acts.

This experiment shows that electricity makes a bar of iron magnetic by acting around it.

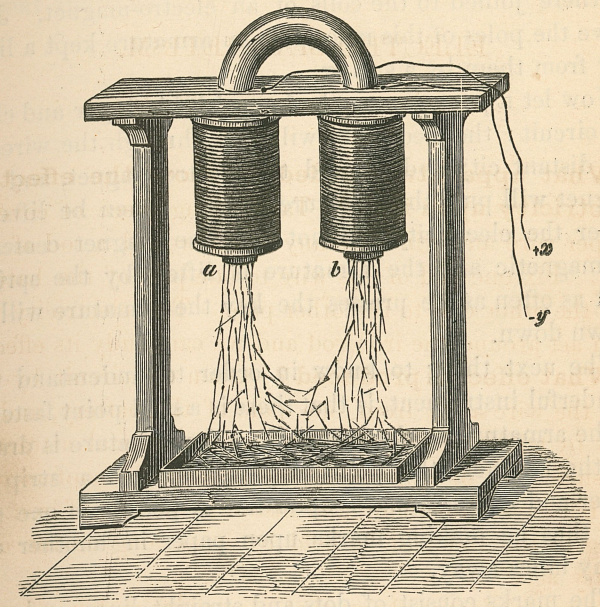
What are such magnets called?—Such magnets are called *electro-magnets* because their magnetism is caused by electricity.

In what form are they usually made?—These electro-magnets are generally made in the shape of the horse-shoe magnet, and the wire is wound a great many times around each branch.

In the picture (Fig. 89) we see one of the electro-magnets fastened in a frame.

This picture also shows the result of a curious experiment. A box of nails is shown below. This box was lifted until the magnet touched the nails and then was

Fig. 89.



slowly let down again. The magnet lifted all the nails it touched: these nails lifted others, and others then clung to them until, as you see in the picture, a chain of nails hung from the ends of the magnet and rested upon the box below.

How long will the iron stay magnetic?—Just at the moment the electric circuit is opened the nails will drop, every one into the box. The iron will be a magnet only while the electricity is acting around it.

What instrument acts on this principle?—The

electric telegraph acts upon this principle. In one city there is a "key" by which a person may open and close an electric circuit as often as he pleases. The wires of this circuit reach over the country to a distant city and are there joined to the coils of an electro-magnet. Just above the poles of this magnet is an armature kept a little way from them by a spring.

Now let a person press the key with his finger and close the circuit: the electricity will dart through the wires to the distant city and around the electro-magnet, and the magnet will pull the armature down. When he lifts his finger the electricity will not act; the magnet ceases to be magnetic and the armature is lifted by the spring. Just as often as he presses the key the armature will be drawn down.

The next thing to know in order to understand this wonderful instrument, is that there is a steel point fastened to the armature, so that every time the armature is drawn to the magnet, the point is pulled against a strip of paper and makes a mark upon it. A person in one city can thus be making marks upon paper in another city many miles away.

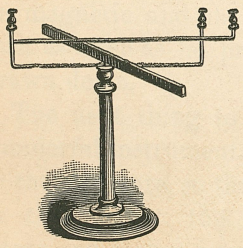
The marks consist of dots and straight lines, and each letter of the alphabet is represented by some arrangement of these marks. For instance, a dot followed by a dash, thus: - —, means A; and a dash followed by a dot, thus, — - stands for N; while a dash and two dots — - - stands for D. You see, then, how the man at the key may write the word AND by making these dots and dashes. It would look like this, - — — - — - -, and one who knows the alphabet by dots and dashes can read these characters even when a thousand miles away from the place from which the message is sent.

This description is only an outline of the plan of the electric telegraph. Every boy and girl should seek a chance to *see* the instrument itself, for from it can be learned, better than from any book, just how the messages are sent and taken.

THE GALVANOMETER.

Describe Oersted's experiment.—A slender bar magnet is placed in a rectangle of wire, which is provided with binding-posts (Fig. 90). Let the magnet stand parallel to the wire, and it is found that whenever a current flows through the wire the magnet will turn upon its pivot. *The current tends to place the magnet at right angles to the wire.*

Fig. 90.



In what direction does the north pole turn?—The direction in which the magnet turns depends on the direction and position of the current.

If the current passes from south to north *above* the magnet, or from north to south *below* it, the north pole turns toward the *west.* But if the current passes from south to north *below* the magnet, or from north to south *above* it, the north pole turns toward the *east.*

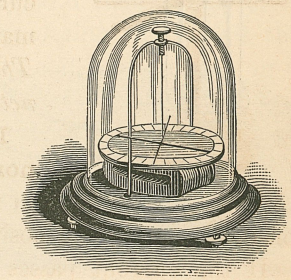
What application is made of this principle?—This principle affords an easy method of detecting the presence of an electric current and measuring its intensity.

The *motion* of the needle shows the *presence* of the current; the *direction* of the motion shows the *direction* of the current; and the *distance* which the pole moves *measures the strength* of the current.

What is an astatic needle?—In order to neutralize the attraction of the earth, which hinders the motion of the needle, two needles are fastened together, with the north pole of each opposite the south pole of the other. The ends of such a compound needle are equally attracted and repelled by the earth. But the north pole is usually left a little stronger than its companion south pole, so that the earth's magnetism is not quite neutralized, and the needle will be "true to the pole" although with a very feeble force. Such a needle is called an astatic needle.

Describe the galvanometer.—A galvanometer is an instrument by which to detect and measure the strength of an electric current. A sensitive form of the instrument is shown in Fig. 91.

Fig. 91.

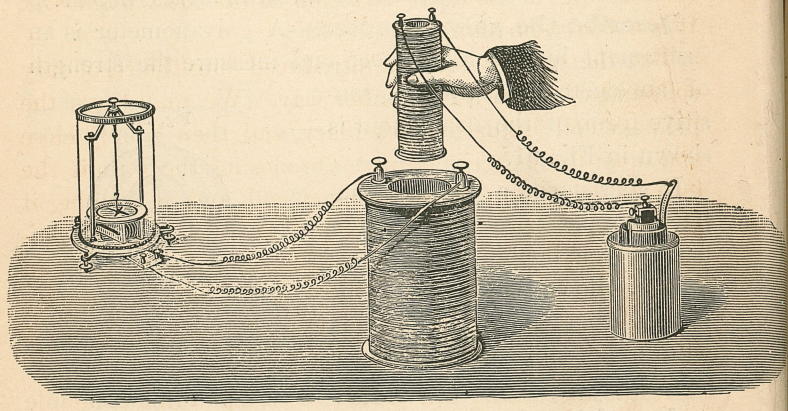


It consists of a coil of insulated copper wire wound on a flat, wooden bobbin, with an astatic needle suspended by a silk fiber, so that the lower needle is within the coil while the upper one lies just above the upper surface of it. A graduated circle is placed under the upper needle, and the whole is covered with a glass shade to protect it from currents of air which would waft the needle. The ends of the coil are joined to binding-posts, not shown in the cut, by which it may be thrown into circuit.

INDUCTION.

What is an induced current?—A current of electricity may be produced in a coil of fine wire by the influence of another current, or of a magnet. A current so produced is called an induced current. It is also called a secondary current.

Fig. 92.



Describe apparatus for induction by a current.—Two coils, one containing a few feet of stout copper wire, and called the *primary* coil, and another containing many feet of fine copper wire, and called the *secondary* coil, are so made that the primary may be placed inside the secondary or taken out at pleasure (Fig. 92). The primary is joined to a battery; the secondary to a galvanometer.

State results of experiments.—While the primary is *passing into* the secondary coil, the galvanometer needle swings, showing a current in the secondary moving in a direction *opposite to that of the battery current.* It is called an *inverse* current.

While the primary is being *withdrawn*, the needle swings the other way, showing a current in the secondary coil moving in *the same direction as the battery current.* It is a *direct* current.

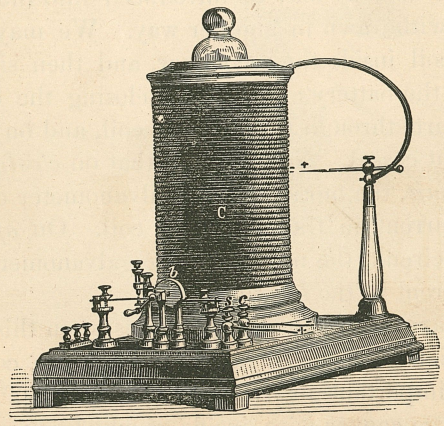
But the current may be introduced into the secondary coil, and withdrawn in another way. We may leave the primary coil inside the secondary, and then simply close and open the battery circuit. On closing the circuit the current darts through the primary coil, and on opening it the current ceases. Now we find that on *closing the primary circuit*, the motion of the galvanometer declares an *inverse* current in the secondary coil. On *opening the primary* circuit, the motion of the galvanometer shows a *direct* current in the secondary coil.

What are induction coils?—It is upon this principle of induction that the *Ruhmkorff coils* are constructed. In these important instruments there is first a primary coil of large copper wire, inside of which is put a bundle of iron wires. Outside of this is placed the secondary coil, which is made of fine copper wire many thousands of feet in length. The two coils are insulated from each other with the utmost care. The ends of the primary coil are attached to the battery, while from the ends of the secondary coil the electricity is taken in experiments.

Describe Ritchie's induction coil.—The induction coil, as constructed by Ritchie, is represented in Fig 93.

The primary consists of about 200 feet of stout copper wire. The secondary contains about 68,000 feet of fine copper wire. The two are separated by a thick glass bell whose knob is seen at the top. The primary circuit is opened and closed by a toothed wheel, *b*. The ends of the secondary are fastened to sliding rods on glass supports. When the poles of a battery are placed in the binding-posts *s* and *c*, let the circuit be opened and closed by turning the toothed wheel *b*, and electric sparks in rapid succession will leap through the air between the

Fig. 93.



ends of the insulated rods marked + and — in the picture. The distance between these points measures the length of the spark, and this depends upon the size and insulation of the coils, and the strength of the battery. The instrument just described is able to yield a spark nine inches in length.

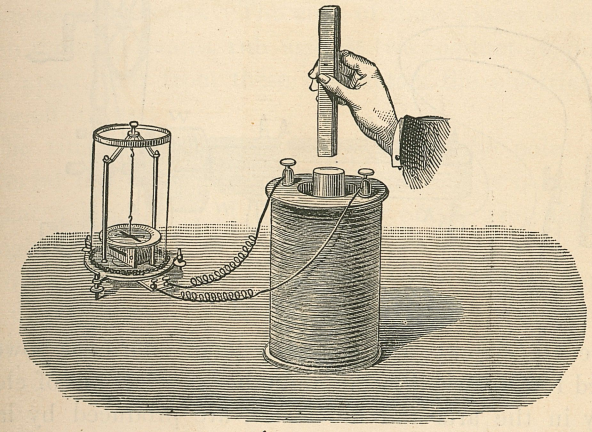
How may induction by a magnet be shown?—Thrust the north pole of a magnet, instead of the primary

coil, into the secondary coil, represented in Fig. 92, and the galvanometer needle swings. Thrust the south pole into the coil, and the needle swings the other way. As the pole of either name is coming out of the coil the needle swings also, but in a direction opposite to that taken when the same pole is passing in.

Hence the motion of a magnetic pole induces a secondary current in a coil, in one direction when it enters, and in the opposite direction when it emerges.

State some further results of experiment.—If a bar of soft iron be placed in the secondary, and then a

Fig. 94.



pole of a magnet be moved toward and from it (Fig. 94), the same effects will be produced. The soft iron becomes a magnet by the approach of the pole, and loses its magnetism when the pole departs. This is, in effect, only another way to introduce and withdraw the magnet.

Finally, insert a *permanent magnet* in the secondary

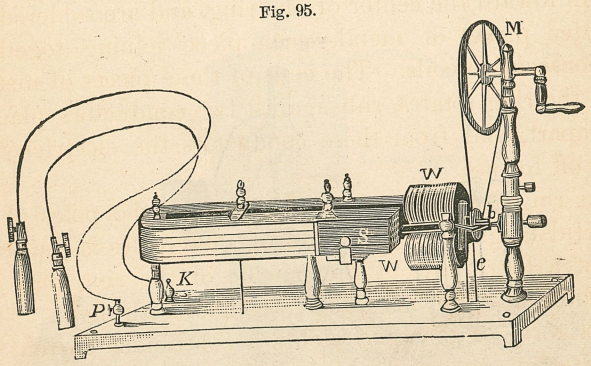
coil, and move a bar or disk of *soft iron* toward and from its pole: currents in the coil are induced by this motion.

The soft iron becomes magnetic by induction, and then affects the magnet in the coil, *strengthening* it by approach and *weakening* it by departure.

Hence any *change in the strength of a magnet will induce an electric current in a coil which surrounds it.*

What is magneto-electricity?—Electricity induced by a magnet is called magneto-electricity. Many forms of apparatus have been devised with which to generate

Fig. 95.



magneto-electricity, and the currents of enormous power, needed for electric lighting and other applications of electricity in the arts and industries, are produced by late and powerful forms of these "*dynamo-electric machines.*"

Describe a simple form.—Two coils of wire, W, (Fig. 95) inclose the two arms of a bar of soft iron, having the form of a horseshoe magnet, which by a band and wheel, M, can be put in rapid motion in front of a very powerful compound magnet, S. The soft iron becomes magnetic whenever its ends are in front of the

poles of the permament magnet, and hence its two branches are being alternately magnetized in opposite states at every turn. The effect of this is to produce two opposite currents in the coils at every revolution. These currents are taken by the wires, *e*, and thence under the instrument to the screw-cups, K and P.

Give a general description of the Gramme machine.—The chief peculiarity of the Gramme machine is to be found in the armature, which consists of a *soft iron ring*, upon which are wound a large number of coils of fine copper wire. The ends of the wire of these coils are bent in toward the center of the ring, and are soldered to insulated pieces of metal—each piece joining together two consecutive coils. The ends of these pieces of metal, when the ring rotates, rub against two conductors placed 180° apart, and from these conductors the electricity is taken off for use.

The ring is made to rotate between the poles of a powerful magnet. The inside of these poles is concave, so that a large part of the outside of the ring may be brought almost, but not quite in contact with them.

This form of machine yields a continuous current in one direction as long as the motion of the armature is continued. (See Ganot's Physics, 1877, p. 798.)

TELEPHONY.

What is the string telephone?—The string telephone is an instrument in which a string will carry the voice of a speaker so that even a whisper can be heard many feet away.

How can it be made?—We first take two small tin cans or boxes, remove their bottoms, stretch a piece of moistened paper smoothly and tightly over the open end of each and fix it securely with a string. We next pierce a small hole through the middle of each of the paper bottoms and then thrust an end of a string, fifteen or twenty feet long, through each of these holes. The ends may be kept from slipping out by tying each around a bit of stick.

How is it used?—If two persons stand apart far enough to straighten the string, one may speak into the open end of the box he holds while the other places the open end of his box against the ear. Even a whisper may be heard distinctly.

Explain its action.—In the first place, the voice of the speaker vibrates the air in front of his lips and his box is filled with air-waves. The air springs back and forth against the bottom of the box, and the elastic paper is made to vibrate just as fast.

In the second place, the string transmits these vibrations to the paper at the other end, which vibrates also with the

same rapidity, although with less amplitude, some of the motion being absorbed on the way by the string.

In the third place, the vibrations of this paper disk throw the air of the box into vibration, and the air waves thus made enter the ear and enable the listener to hear what his companion whispers.

What should we particularly notice?—The air-waves which enter the ear of the listener are like those which are produced by the speaker's lips. In passing from air to paper, from paper to string, from string to paper at the other end, and from paper there to air again, the vibrations are unchanged, except in amplitude, which is less and less as the string is longer, and hence the air-waves which enter the ear are just like those which leave the speaker's lips, except in amplitude, and on this account the sound which is heard is the same as that which is uttered, except in loudness.

What principle does this illustrate?—Every sound is a series of waves having a certain rate, a certain amplitude, and a certain form, and whenever this series of waves enters the ear the same sound will be heard.

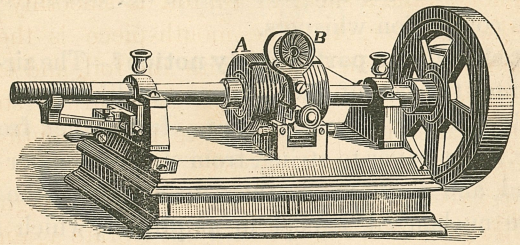
If a piece of paper, or a disk of metal, or anything whatever, can be made to copy exactly the vibrations in the voice of a speaker, it will imitate that voice and utter words.

What instrument illustrates this principle?—The phonograph, or "Edison's talking machine," illustrates this principle. It makes a record of any words which are spoken into it, and will reproduce these words whenever called upon to do so.

Fig. 96 represents the phonograph, and Fig. 97 shows a section of its principal parts.

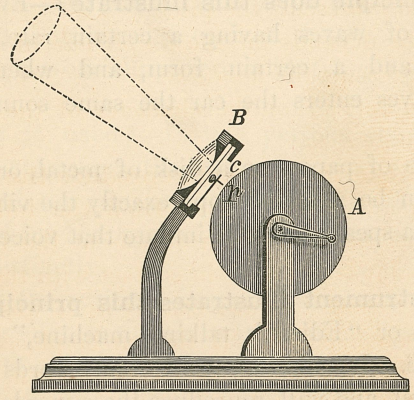
Describe the phonograph.—A metallic cylinder, A, is supported on a long axle so that it can be easily turned by a crank. At one end of the axle is a screw-thread

Fig. 96.



which fits into a corresponding thread of the support, so that when the cylinder is turned it will also move forward. A spiral groove is cut in the surface of the cylinder.

Fig. 97.



In front of this cylinder is a mouth-piece, B. In this mouth-piece is a thin circular disk of metal, fastened at its edges. Under the center of this disk or diaphragm is

a needle-point, *p* (Fig. 97), fastened to the end of a delicate spring, and between it and the diaphragm is a small piece of rubber tube.

How does this instrument record the voice?—To use the phonograph a sheet of tin-foil is smoothly wrapt around the cylinder, A. The mouth-piece is then set with its needle-point in contact with the foil, and exactly over the groove. The cylinder is then turned steadily while the speaker puts his lips close to the mouth-piece, and utters his words in a loud voice.

The air-waves of the voice vibrate the diaphragm, and the diaphragm makes the needle-point vibrate against the tin-foil, which it presses more or less deeply into the groove beneath. These depressions follow the groove around the cylinder, and constitute the record of the voice.

The *closeness* of the depressions depends on the *rate* of vibration, and represents the pitch.

Their *depth* depends on the *amplitude* of the vibrations, and represents the *loudness*.

Their *form* depends on the character of the wave, and represents the *quality*.

How does the instrument reproduce the voice?—The needle-point is first lifted from the foil, and the cylinder turned back to where it was at the beginning. The needle-point is again set in contact with the foil, and the cylinder turned forward exactly as it was while the words were being spoken. If the ear be placed near the mouth-piece, or better, if a long cone, shown by dotted lines in the figure, be used, the words spoken to it will be heard spoken back again by the phonograph.

The needle-point must follow the tracing, rising and falling as it passes over the indentations which it made in

its former passage over the foil. This vibration of the point is communicated to the diaphragm, and its vibrations produce the air-waves which enter the ear.

How does this illustrate the principle?—The diaphragm vibrates, when the point follows the indentations, just as it did when the voice was thrown against it; hence the air waves it produces must be like those which fell upon it, and it speaks back the words which it received.

What is a telephone?—In the phonograph the record of the sound is permanent, and the sound can be reproduced at any time afterward; but in a telephone the sound is reproduced at the time it is made, without leaving a record. A vibrating diaphragm is made to produce air-waves like those which are produced by the lips of a distant speaker, and thus to utter his words into the ear of a listener. Any instrument for transmitting sound on this principle is a telephone.

Of what two parts does a telephone consist?—In every telephone there is a *transmitter* into which the voice is uttered, and a *receiver* at the distant station where the listener hears it.

By what agent are the vibrations in the transmitter repeated in the receiver?—These two parts of the telephone are joined by an insulated wire like the telegraph line, and the vibrations in the transmitter are reproduced in the receiver by an electric current.

What are the two classes of telephone?—The instruments in general use belong to two classes. These are *magneto* telephones, in which the electricity is generated by a magnet, and *electro-chemical* telephones, in which it is supplied by a battery.

The Bell telephone belongs to the first of these classes

and Edison's carbon transmitter to the second. These are the instruments in most general use.

Describe the Bell telephone.—Fig. 98 represents this instrument. It looks like a round wooden box, with a

Fig. 98.

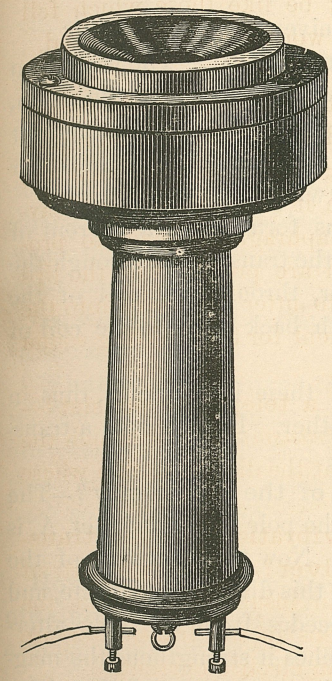
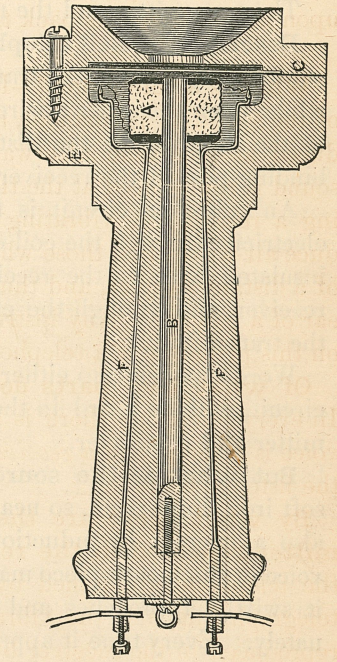


Fig. 99.



mouth-piece on the top and a long wooden handle with binding-posts attached to the bottom.

Fig. 99 shows a section through the center lengthwise of the instrument, and shows the arrangements of its parts. B is a bar magnet, and A is a coil of fine wire

encircling one of its poles. The ends of this fine wire are fixed to the wires, F, F, which lead to the binding-posts outside. A thin sheet or diaphragm of soft iron, C, lies in front of the pole of the magnet, as near as it can be without touching it, and, just opposite the pole, on the other side of the diaphragm, is the small opening of the conical mouthpiece.

The transmitter and the receiver are exactly alike.

Describe the Bell telephone circuit.—The wire from one binding-post of the transmitter reaches to the earth, while from the other a wire extends to one binding-post of the receiver at the distant station. From the other binding-post of the receiver a wire passes to earth.

An unbroken circuit is thus formed for a current of electricity through the coil of the transmitter, through the insulated wire to the receiver, through the coil of the receiver, and through the earth back again to the coil of the transmitter.

Words spoken into either of these instruments, thus in circuit, will be heard in the other. Each is both a transmitter and a receiver.

But what is the source of the electricity?—The soft iron diaphragm, so near the pole of the magnet, A, is also a magnet by induction. Now the air-waves of the voice in the mouth-piece make this diaphragm vibrate, and it swiftly approaches and recedes from the pole alternately. Every time it approaches it strengthens the magnetism of the pole, and this induces a current of electricity in the coil. Every time it leaves the pole it weakens the magnetism, and a weaker current is made in the coil. A current of irregular strength, or an undulatory current, is thus sent through the circuit, from the transmitter, by the vibrations of its diaphragm.

How does this current affect the receiver?—When the strong part of the current passes around the pole of the magnet in the receiver the pole is strengthened, and it attracts the diaphragm near it more strongly, and when the weak part of the current passes, the pole is weaker and the diaphragm is attracted less. By this irregular attraction of the magnet the diaphragm of the receiver vibrates.

The vibrations of the diaphragm of the transmitter have the same rate and character as the sound-waves in the mouth-piece. The vibrations of the diaphragm in the receiver are faithful copies of those in the transmitter, and the air waves in the receiver have the same rate and character as the vibrations of the diaphragm which produce them. Hence the sound-waves from the receiver must have the same rate and character as those of the voice which enters the transmitter, and must affect the ear in the same way.

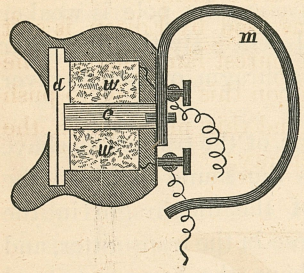
What is transmitted?—Nothing but electric pulses go from one instrument to the other. The sound-waves are changed into electric pulses by the transmitter, and these electric pulses reaching the receiver are changed back again into sound-waves.

How are different forms of magneto-telephones obtained?—By varying the shape of the magnet, and the arrangements of parts, a variety of forms of telephone have been constructed.

A single example may be given to illustrate this. In Fig. 100 a short iron core, *c*, is wound with a coil of wire, *w*, the ends of which are joined to the binding-posts. One pole of a strong magnet, *m*, is firmly fixed in contact with the outer end of the core. The core thus becomes a mag-

net by induction, and the diaphragm, *d*, by vibrating in front of it, sends the electric current through the wire. The magnet, bent into semicircular form, serves as a convenient handle for the instrument.

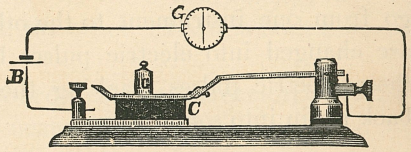
Fig. 100.



What principle is applied in Edison's carbon telephone?—The resistance which carbon offers to the passage of a current of electricity varies with the pressure upon it.

This principle may be illustrated by apparatus represented in Fig. 101. The carbon, C, is placed between two pieces of metal to which binding-posts are attached. B represents a battery, and G a galvanometer. When the circuit is closed a current flows from the battery through the carbon and the galvanometer, and the strength of this current is shown by the deflection of the galvanometer needle. Now let a greater weight be placed upon the upper plate and the needle swings further, showing a stronger current; or let a smaller weight be used, and the needle swings a less distance, showing a weaker current.

Fig. 101.



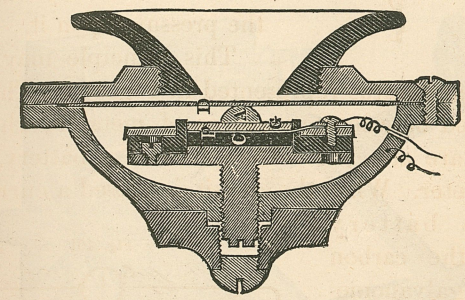
It would seem, therefore, that the resistance which the current meets in the circuit is less when the pressure on the carbon is greater.

If we ask, further, *how* pressure can increase the conductivity of the circuit, we may answer that the effect of

pressure is *to bring the parts of the circuit into closer contact.* If the two pieces of metal touch the surfaces of the carbon at few points, the electricity flows with difficulty; if at many points, it flows more easily.

Moreover, the carbon itself, as used by Edison, is soft carbon, made by compressing the purest lamp-black. The effect of increasing the pressure upon this must be to push its particles into closer contact, and this must lessen the resistance to the passage of electricity.

Fig. 102.



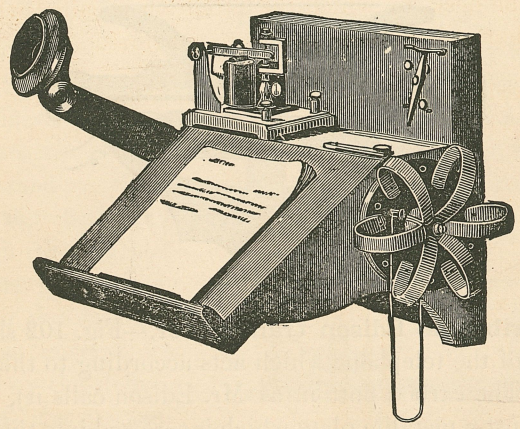
Describe the Edison transmitter.—Fig. 102 shows a section of the telephone which acts according to this principle. The carbon button (as Mr. Edison calls it), C, lies flat against a metallic plate which is screwed into the metal frame of the instrument. On the other side of the carbon is a disk of platinum, P. This is insulated. The diaphragm, D, presses against the platinum through a glass plate, G, and the projecting knob, A. A wire to the platinum plate and another from the metallic frame bring the carbon into the electric circuit. One of these wires leads from a pole of the battery, the other may join the line reaching the receiver at the distant station while the other pole of the battery is joined to earth. Much better

results, however, are produced by making the carbon a part of the primary circuit of a small induction coil, and the line wire and distant receiver a part of the secondary circuit.

This instrument is used as the transmitter, while the receiver is a Bell or some other form of the magneto-telephone.

Explain the action of the transmitter.—The sound-waves thrown by the lips into the mouth-piece fall upon

Fig. 103.



the diaphragm, and the vibrations are transmitted to the platinum plate. The delicate vibrations of this plate against the carbon button is a varying pressure upon it, and this varying pressure varies the strength of the current which is passing through it.

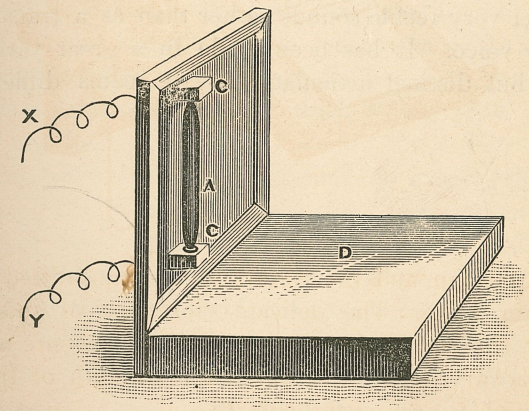
The receiver, therefore, receives an undulating current which affects its magnet, and produces the sound-waves just as if it were in connection with a magneto-transmitter.

How is the telephone arranged for actual use?—At each station there is both a transmitter and a receiver, so that a person can keep one to the lips and the other to the ear during the conversation. A convenient arrangement is shown in Fig. 103.

An Edison transmitter is fixed to a jointed arm, so that it can be put in any position to suit the speaker. The receiver shown is a Phelps telephone, which, when not in use, is hung on the side of the desk. An ordinary telegraph sounder, or more commonly an electric bell, stands upon the desk, by which the attention is called whenever a speaker at a distance wishes to converse.

Describe the microphone.—The microphone is a transmitter which consists simply of a rod of carbon, A (Fig.

Fig. 104.



104), pointed at both ends and supported between two small blocks of carbon, C,C, with its ends resting in shallow cups. The whole is fastened against an upright, thin board fixed upon a solid base, D. The carbon is put into

circuit by joining one block to a pole of the battery by a wire, Y, and the other to the line leading to the distant receiver by another wire, X.

Sound waves falling against the upright carbon make it vibrate, and the strength of the passing current is varied by these vibrations. The ticking of a watch, or the steps of a fly moving over the board can be distinctly heard far away in the receiver.

The upright carbon touches the blocks in comparatively few points, and the resistance of the circuit is considerable. The number of points of contact are increased and diminished by the vibrations of the carbon, and the resistance varies accordingly. The strength of the current varies, therefore, in obedience to the sound-waves which agitate the carbon.

The microphone is exceedingly sensitive, and is useful to detect very feeble sounds rather than as a transmitter for the voice. It has been made in a great variety of forms, but distinct articulation by it seems difficult to reach.

ENERGY.

What is work?—Whatever requires an effort is work. Work is the overcoming of resistance of any kind. In science the word has a more precise meaning than in common use. To throw a ball, to lift a weight, to run a race, is to do work, and we know that in some cases we do harder work than in others. But in science we measure work more precisely, and give it a numerical value.

How can we measure work?—We must first adopt some unit. We must take some particular amount of work and call it one, and then we can compare other amounts with this, and find how many of these units they contain.

I do a certain amount of work whenever I lift one pound one foot high, and if I should do it over again a hundred times I should each time do exactly the same amount. The work done in lifting *one pound* to the height of *one foot* is called a FOOT-POUND. This is the unit in measuring work.

Give illustrations.—Suppose, for example, that a pail of water weighs ten pounds, and that I lift it from the floor to the first step of the stairs, a height of one foot; I have done ten times as much work as would have been done if the weight had been only one pound. I have done ten foot-pounds of work. If I lift the ten pounds up another step of the same height, I also do another ten foot-pounds of work, and in lifting it up the two steps I

have done twenty foot-pounds. This value 20 equals 10×2: that is, *the work done is found by multiplying the weight lifted by the vertical height through which it is raised.*

But suppose the weight is not moved vertically?—Still we can measure the work done by the same rule, because we can first find how far the same effort would be able to raise it vertically, and then multiply its weight by this. For example, I walk up stairs; the work I do in carrying myself up is not the product of my weight by the *length* of the stairs; it is, however, the product of my weight by the vertical distance between the floors.

And so, when work is done in any direction whatever, we may find to what vertical height the body would be lifted against gravity with the same amount of work; and then the weight of the body multiplied by this height is the amount of work done.

What is energy?—By energy we mean the ability to do work. When a nail is driven into wood the moving hammer does the work. It is true that the ability to do this work is at first in the hand which wields the hammer; but the hand gives this ability to the hammer, and it is the hammer that finally drives the nail. The *hammer in motion* is able to overcome the resistance of the wood, and this *ability to do work* is its ENERGY.

Every moving body is endowed with energy.

Upon what does energy depend?—We may answer this question by studying the energy of the hammer a little longer.

Suppose a larger hammer is used: evidently the nail would be driven further by the blow; it would do more work. In other words it would have more energy.

Hence *energy depends on the mass of the moving body.*

But suppose we use the same hammer, and make it fall faster in coming down upon the nail; evidently the nail would be driven further by the blow. More work would be done than when the hammer was brought down slowly.

Hence *energy depends on the velocity of the moving body.*

What is the law?—We thus find that energy depends on both mass and velocity. It depends on these two things alone, and its relation to them is stated in the following law:

(The energy of a moving body is proportional to its mass and the square of its velocity.)

What is the relation of energy to work?—We have seen that work means simply the overcoming of resistance. *Time* is not taken into account in estimating work. To place a ton of merchandise upon a freight car the same *amount* of work must be done, whether it is done in one hour or in ten hours.

But they who have done the work in one hour are more fatigued than if they had spent ten hours instead. They have expended more energy. To do work fast requires more energy than to do it slowly. Time is thus seen to be an element in computing energy.

What must be known to find energy?—Before we can compute the energy of a moving body we must know its mass and its velocity. By knowing its velocity we can find the *vertical* height to which the body would rise if it should start upward with this velocity, and it is necessary to do this because the unit by which its energy is measured is the energy required to *raise* a pound weight a foot *vertically.* Now this vertical height is found by dividing the square of the velocity by $64\frac{1}{3}$.

How, then, is energy computed?—By multiplying the weight of the moving body by the square of its velocity, and dividing the product by $64\frac{1}{3}$.

The value obtained is the total *work* which the body can do before its motion is exhausted, and this measures its ability to do work, or its energy.

Do bodies at rest possess energy?—A body may possess energy not only when it is in motion, but even when it is at rest. When a body is in motion against some resistance *it is expending* the energy stored in it, but it may hold this energy even while at rest, just as a man may possess money which he is not spending.

Under what condition?—A block of iron resting upon a high platform *has power* to overcome resistance. True, the platform prevents the exercise of that power, but the power is in it. Take away the hindrance and the block falls, and in falling is expending the energy which was stored in it while at rest.

The block resting upon the earth has no energy at all; lift it to the platform and it is at once gifted with energy or the power to overcome resistance. The high position is the position of advantage. The block must be placed *at a distance from the earth* in order to be endowed with energy.

What is its energy called?—The energy stored in a body at rest *due to its position* is called POTENTIAL ENERGY.

We have said that this energy is due to the position of the body above the earth, but if there were no *attraction* between it and the earth, it would have no energy. It has energy because it is separated from the earth *which attracts it.*

Define potential energy.—Hence we may give a better definition, one which is universally true, in these words:

Potential energy is *the energy due to the separation of bodies which attract each other.*

What are the two types of energy?—The energy of a body in motion is called KINETIC ENERGY, and all energy is of one or the other of these two types. It is either kinetic or potential.

But can we not distinguish different varieties?—These two types of energy show themselves in a variety of ways, and they may accordingly take different names.

What is mechanical energy?—The energy of a train gliding swiftly along its track, of the waterfall, and of the tornado, are examples of mechanical energy. It is the energy displayed by *masses* of matter. solid, liquid, or gaseous.

What is molecular energy?—But besides this energy in masses, there is energy displayed by molecules. We have reason to believe that *heat* is the energy of molecules which swiftly move among themselves while the body is at rest.

It is well known, for example, that a nail, lying upon an anvil, may be intensely heated by the blows of a hammer. Now we suppose that the molecules of the nail tremble under the blows, more and more as they are repeated, and that the heat we feel is the energy of this molecular motion expended against the hand.

What is chemical energy?—Not only masses and molecules, but atoms also exhibit energy. Between the atoms of oxygen in the air and the atoms of carbon in fuel there is a strong attraction. In the cold this attraction is unable to bring these unlike atoms together; they are in a condition like that of the earth and the block of iron which is kept from falling; their energy is *potential.*

But if the atoms of oxygen and carbon are allowed *to fall together*, as the block falls to earth, their energy becomes *kinetic*.

This is what happens when coal burns in our furnaces. Whatever power is obtained from fire is primarily due to the motions of atoms. It is the chemical energy in the fuel that drives the engine of the locomotive, of the steamship, and of the manufactory.

What is radiant energy?—When a cord vibrates, its energy is gradually taken away by the air, until finally exhausted, when the vibrations are at an end. When a bell is struck its molecules vibrate, but the energy in this motion is gradually given up to the air until exhausted.

By these and all other vibratory motions, undulations or waves are produced, and these undulations possess all the energy which the vibrating body has given out.

The energy exhibited by undulations, in whatever medium they exist, is called *radiant* energy, because the waves pass from their source outward in all directions; they radiate. Radiant energy is that which is transmitted by undulations.

What are the manifestations of radiant energy?—Waves in air affect the ear as sound; sound is a manifestation of radiant energy.

Waves in the ether affect the eye as light, and the sense of touch as heat: light and radiant heat are also manifestations of radiant energy.

What is electrical energy?—The power of electricity to overcome resistance is seen in the motions which this agent produces when applied in various ways, and the energy exhibited by electricity is called *electrical* energy.

What happens when a moving body strikes another?—In rolling marbles, when one strikes another it stops, and the other bounds away. The energy passes from one into the other. Place three or four in a row against the edge of a "ruler" to keep them in line, and then roll another violently against the end of the series. The ball at the other end bounds off, while the others remain at rest. The energy of the one you throw is *transmitted* from ball to ball until it reaches the last, which keeps it all, except what it gives up to the air and the table, which resist its motion.

Whenever a body in motion meets an obstacle, energy is transmitted to it.

Illustrate the transmutation of energy.—Let a ball be shot vertically upward: on starting, its energy is kinetic. But it rises more and more slowly until it stops, and then falls again to the ground. Now, at the moment it stops at the top of its path, its energy is potential. During its flight upward kinetic energy changes into potential energy; and again, during its fall, potential energy is changed into kinetic energy. There is no loss, but simply a change in the character of the energy.

Observe a swinging pendulum, and notice a similar transmutation of kinetic and potential energy.

Or take the case of the nail which is warmed by the blows of a hammer. The *mechanical energy* of the hammer is not lost when the hammer stops: it has been changed into *molecular energy*, or *heat*.

Whenever energy disappears, it has been transmuted into another form.

What important fact in these changes?—The motion of a sledge-hammer can give rise to a certain amount of motion among the molecules of the anvil on which it

falls,—no more, no less. The energy of the hammer is changed into molecular energy: it appears as heat. Now, if this heat could be all collected, and changed back into mechanical energy, it would be just sufficient to lift the hammer to the height from which it fell. The amount of heat produced by a given energy will always be the same, and when it disappears it can exert an energy just equal to that which caused it. *Nature permits no loss in her exchanges.*

What is the mechanical equivalent of heat?—Is it, then, possible to tell just how much heat will be produced by a given amount of mechanical energy, or how much energy a given amount of heat may exert? This has been done with the greatest accuracy.

It has been found that if a pound weight, after falling a distance of 772 feet, should be instantly stopped, it would evolve heat enough by the blow to raise the temperature of one pound of water just one degree Fahrenheit. The energy expended in this blow would be 772 foot-pounds, and this, changed into heat, is equal to the thermal energy needed to raise a pound of water 1° F. in temperature.

Or when heat is changed into mechanical energy, if the heat needed to raise the temperature of a pound of water 1° F. could be all applied mechanically, it would be competent to raise a pound weight to a height of 772 feet, or it would raise 772 lbs. *one foot:* it is equal to 772 foot-pounds of work.

Then 772 foot-pounds is what is called the MECHANICAL EQUIVALENT OF HEAT.

State the law of conservation of energy.—Energy may be transmitted from one body to another, or transmuted from one variety into another, but it cannot be destroyed nor created. The sum total of energy in the universe is constant.

How is this true in machinery?—The work accomplished by any machine can never be greater than the work done to keep it in action. If a small power overcomes a larger resistance it must move *faster*, so that the product of itself by the vertical height corresponding to its velocity may equal the product of the resistance by the vertical height corresponding to its velocity. No more work can be got out of a machine than is put into it. Indeed, in practice much less is realized, because the power must not only impart all the energy which the machine expends in doing its work, but it must also expend energy to overcome the friction and other resistances of the parts of the machine itself.

Why is perpetual motion impossible?—No machine, however simple or complex, can move without doing work, because, even if we give it nothing else to do, there is resistance of the air and the friction of its own parts, which it is impossible to entirely remove. Energy is expended in overcoming these resistances, and when all the energy which has been put into it is used up the machine must stop. A perpetual motion in the sense of a machine which, when put in motion, will move indefinitely without additional power, is therefore an impossibility.

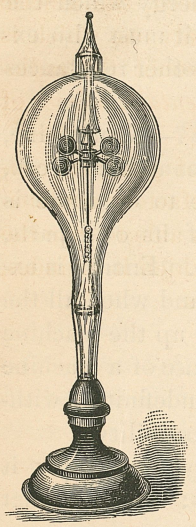
A machine may transmit our energy, and apply it advantageously in doing a piece of work: this is all that any machine can do.

What is the kinetic theory of gases?—It is believed that gases are made up of molecules separated by distances very great when compared to the size of the molecules themselves, and that these molecules are moving

with very great velocity. Moreover, it is thought that while they are darting in all directions yet that the motion of each one is in a straight line until it comes into contact with another molecule, the side of the vessel, or some other obstacle, and that on striking another or any obstacle it bounds away in another straight line until it again comes into collision. Heat increases the velocity of this molecular motion.

What is the pressure of a gas?—It is easy to see that if this theory is true the molecules of air must be continually pounding against the walls of the vessel which contains it; or, indeed, against everything which it touches. Every little blow exerts a little pressure, and such a multitude of swift blows is a constant pressure. Indeed, on this theory, the *pressure* of air or of any gas is nothing more than *the energy of its molecular motion.*

Fig. 105.



What is the radiometer? — The radiometer (Fig. 105) is a small, glass globe with a very light vane resting on a pivot in the center. Each one of the four arms of the vane carries a disk of aluminum which is white on one side and black on the other. The air in the globe is exhausted to a very perfect vacuum. Let this instrument be placed in the sunbeam or near the flame of a candle and the little vane will spin around with surprising swiftness, the bright fans of the disks always going ahead.

What is the explanation of this motion?—The kinetic theory of gases gives a reason for this motion of the vane, for when the air is so greatly rarefied there can be no convection currents to affect the vane, and its disks receive the blows of the few molecules which remain. The sunbeam heats the black faces of the disks more than the bright faces, and heat increases the energy of the molecular blows. Thus it happens that there is a greater energy against the dark faces than in the opposite direction, against the bright faces and this energy moves the vane.

The motion of the vane in the radiometer under the influence of the sunbeam is a fact which no theory can explain so well as that just given. Indeed, the kinetic theory of gases would seem to be the only one which is competent to explain it, and on this account the radiometer is to be looked upon as an *experimental evidence* of the truth of our molecular theory.

Moreover, all the known phenomena of gases are consistent with this theory, and find no satisfactory explanation in any other. So long as a theory is able to give the best explanation of all the phenomena which it includes, it will be accepted in preference to others.

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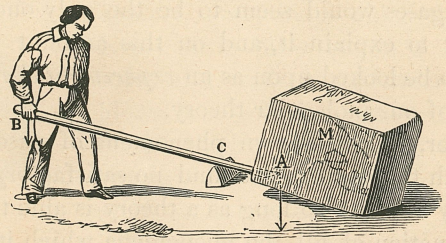
Dep. B.

MACHINERY.

What is shown in Fig. 106?—In Fig. 106 we see the picture of a man trying to move a block of stone. It is much too heavy for him to lift, and you notice that he has taken a long bar to assist him. Putting one end of it under the stone, and resting the bar upon a block C, he pushes down upon the other end, and in this way lifts the stone.

Fig. 106.



Explain the action more fully.—We see that the bar rests upon the prop C, and that the end B cannot be pushed down without moving the other end A, up. Now when the part C B is so much longer than the part C A, the man by his own weight can lift a stone very much heavier than he himself is.

What is this bar called?—This bar is called a *lever*. This name is given to any bar that can be used in this manner. A *lever* is an inflexible bar which can turn freely upon a pivot or prop.

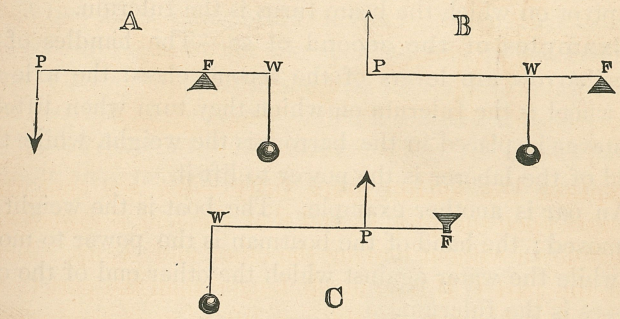
Define Power, Weight, and Fulcrum.—The strength which the man exerts at B is called the *power;* we speak

of the stone to be moved as the *weight*, and call the prop C the *fulcrum*.

Levers are not always moved by hand, nor are they always used to move stones, and yet these same terms are used. The *power* is any force by which the lever is to be moved. The *weight* is any resistance which is to be overcome. The *fulcrum* is the support on which the lever moves.

What does Fig. 107 A show?—In Fig. 107 A, the lever is shown without the laborer and the stone. P represents the place of the power; W represents the place of the weight, and F the fulcrum. The fulcrum is in this case between the power and the weight.

Fig. 107.



Is this always the case?—But this is not always the order of arrangement. In Fig. 107 B, the weight W is between the fulcrum F and the power P. The weight being near the fulcrum, is lifted by raising the more distant end of the lever.

In Fig. 107 C, the power is between the fulcrum and the weight. Here also the power must pull upward to lift the weight. Now these three figures represent levers of the three classes.

Describe the three classes of lever.—In a lever of

the *first class* the fulcrum is between the power and the weight (Fig. 107 A). In a lever of the *second class* the weight is between the power and the fulcrum (Fig. 107 B). In a lever of the *third class* the power is between the fulcrum and the weight (Fig. 107 C).

All levers, of whatever form or use, belong to these three classes.

Mention some levers of the first class.—The handle of a common pump is a lever of the first class: the piston and the water are the weight, the hand of whomsoever does the work is the power, while the pivot on which the handle turns is the fulcrum.

The balance of a tradesman is another example: the body to be weighed, put into one scale-pan, is the weight; the weights put into the other pan are the power; while the pivot on which the beam turns is the fulcrum.

Examples of the second class.—The handles of a wheelbarrow are levers of the second class: the axle of the wheel is the fulcrum on which they turn when lifted; whatever is placed in the barrow is the weight, while the hand of the laborer is the power to lift it.

An oar is another example. The boat is the weight to be moved; the hand of the boatman is the power to move it; while the water against which the other end of the oar presses is the fulcrum.

Example of the third class.—When a ladder is raised by resting one end on the ground and lifting upon a round somewhat farther up, it is a lever of the third class. The end on the ground is the fulcrum; the hand of the man is the power; while the weight of the ladder, most of which is beyond the hand, is the weight.

What relation exists between power and weight?—In Fig. 106, if the distance from A, the place where the weight rests on the lever, to C, the fulcrum, is one-fourth the distance from C to B, then the weight may be balanced

by a power only one-fourth as great. The power will be just as many times *less* than the weight as the distance from it to the fulcrum is times *greater* than the distance from the weight to the fulcrum. If the distance of the power from the fulcrum is *ten* times as far as the distance from the weight to the fulcrum, then the weight will be balanced by a power only *one-tenth* as great as itself.

State the law.—This principle, briefly stated, is as follows: "The power and weight will *balance each other* when they are to each other *inversely* as their distances from the fulcrum."

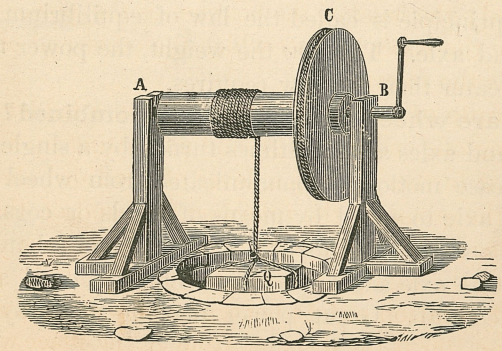
This principle is called the law of equilibrium for the lever. It holds good in all the three classes.

To *move* the weight, the power must be a little greater than this principle would make it.

What is a compound lever?—When two or more levers are made to act one upon another in succession, so that a power applied to the first lifts a weight applied to the last, the instrument is called a *compound lever.*

What does Fig. 108 show?—Fig. 108 shows how a weight may be lifted by fastening one end of a rope to it

Fig. 108.



and winding the rope up on a cylinder. In this way water is often raised from deep wells. By turning the crank

the upper part of the rope is wound upon the cylinder, and the bucket, hooked upon the lower end, is raised.

What often takes the place of the crank?—Instead of a crank B, to turn the cylinder, a wheel C is very often used. The power is applied to the circumference of the wheel, sometimes by means of a rope, sometimes by means of a band, sometimes by means of cogs, and in various other ways.

What are such machines called?—A machine such as represented in Fig. 108, is called a "*Wheel and axle.*" The cylinder upon which the rope winds is the "*axle,*" while the "*wheel*" may be an actual wheel or a crank, both of which are shown in the picture, or it may have other forms still. Whatever shape this part may have the machine is called the "wheel and axle."

What is the relation between the power and the weight?—When the weight is just as many times greater than the power as the radius of the wheel is greater than the radius of the axle, the two forces will just balance. In other words: "The power and weight will balance, when the power is to the weight as the radius of the axle is to the radius of the wheel."

This principle is called the law of equilibrium for the wheel and axle. To *move* the weight, the power must be made greater than this law requires.

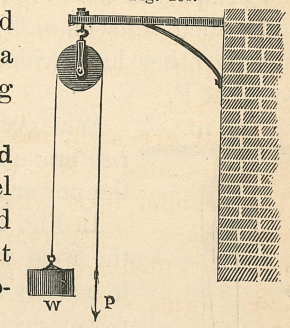
How are wheels and axles often combined?—Many wheels and axles are sometimes turned by a single power. In this case motion is communicated from wheel to axle or from axle to wheel by means of bands or cogs. If by a power on one wheel its axle is turned, and a band passes around this axle and a second wheel, the second axle will be turned also. Great power may in this way be obtained.

How may rapid motion be secured?—If the power be applied to the circumference of the axle instead of

the wheel, and if a band pass around the wheel and a second axle, the second wheel will be put into very rapid motion.

What is shown in Fig. 109?—In this figure we can see how a heavy weight may be lifted by fastening it to the end of a rope which passes up over a grooved wheel, and then pulling downward upon the other end.

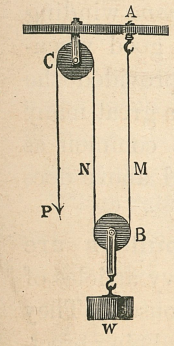
Fig. 109.



What is such a grooved wheel called?—A grooved wheel used for such a purpose is called a *pulley;* and in this case, since it is firmly fastened in a fixed support, it is called a *fixed pulley.*

What advantage in its use?—The only advantage gained by means of the fixed pulley consists in being able to change the direction in which the power acts. A man, for example, can exert his strength to better advantage *pulling downward* than *lifting upward,* and if a load is to be lifted the fixed pulley allows him to use his power in this better way. He gains in no other way; if the load weighs 100 lbs., he must pull with a force equal to 100 lbs., and indeed a little more, since the rope and pulley take up some of his strength to move them.

Fig. 110.

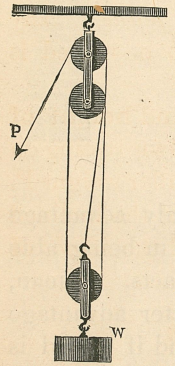


What is a movable pulley?—The case is very different when the pulley is arranged as in Fig. 110. In this arrangement the weight is hung from the axis of the pulley, B, and is to be lifted by means of the rope which is fastened to the beam at A, and then after passing under the pulley B, goes over the fixed pulley C. By pulling upon the rope at P, the pulley B will be lifted and will carry the weight

up with it. A pulley which moves with the weight is called a *movable pulley.*

What advantage is gained?—Now it is easy to see that the weight is held up by the two branches of rope, *m* and *n*, and that each branch holds one-half of it. But the half which rests on *m* is sustained by the beam, leaving only the other half, which rests on *n*, to be lifted by the power at P.

Fig. 111.



When, with a movable pulley, there are *two* branches of rope to sustain the weight, the power may be only *one-half* the weight.

In Fig. 111 there are *three* branches of the rope which hold the weight and share it equally between them. In this case the power need be only *one-third* as great as the weight to balance it.

What general principle does this illustrate?—In all cases the power needed to balance any weight will be found by dividing that weight by the *number of branches* of the rope which supports it.

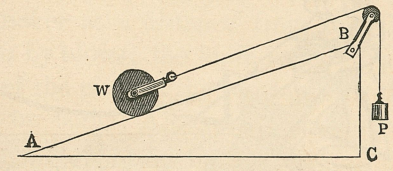
Will this law apply in all cases?—In the cases considered you will notice that there is a *single rope* winding around all the pulleys. Now the law holds good whenever the weight is supported in this way, provided the branches of the rope are parallel. There are a great many other ways of arranging the pulleys, not as common as this, however, and in such cases the law stated above does not hold good.

Mention some purposes for which pulleys are used.—Pulleys are often used for lifting heavy articles of merchandise to the upper stories of warehouses. They may be seen also where buildings of stone are being erected, and heavy blocks are to be raised to considerable height. But more numerous than anywhere else, you will find pulleys on shipboard, where they are used by the seamen in managing the rigging of the ship.

What is an inclined plane?—When a drayman wishes to lift a cask of sugar from the sidewalk to his dray he does not lay hold of it and raise it vertically, as he might do with a lesser weight, but he accomplishes the work far more easily by rolling it up along a plank reaching obliquely from the ground to the dray. The *inclined surface* of the plank is called an *inclined plane.* Any inclined surface over which weights are to be moved is an inclined plane.

What is meant by the terms length and height of the plane?—In Fig. 112 a weight W is shown resting on an inclined surface A B, balanced by a smaller weight P. Now the distance A B is called the *length* of the inclined plane, and the vertical distance C B is called the *height* of the plane.

Fig. 112.



In the plane used by the drayman the length of the plank from the sidewalk to the dray is the length of the inclined plane, while the height of the dray above the walk is the height of the plane.

What relation exists between power and weight?—If the weight W is 100 lbs. and the *height* of the plane is one half the *length*, then the power to balance the weight need be only one-half the weight, or 50 lbs.

If the height is $\frac{1}{10}$ of the length of the plane, the power need be only $\frac{1}{10}$ the weight.

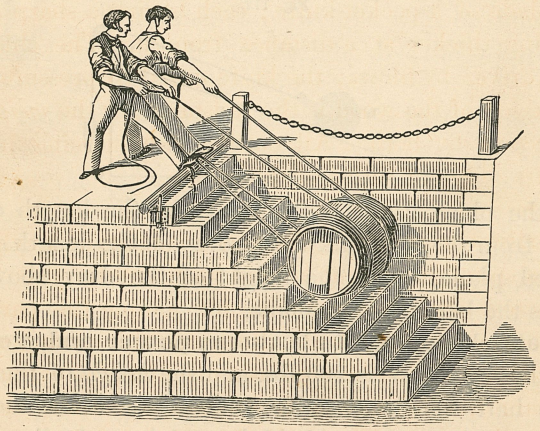
The general principle or *law* is this; the power and

weight will balance when the power is to the weight as the height of the plane is to its length.

Under what conditions will this law hold good?—This law holds good only when the power is exerted in a direction *parallel to the length* of the plane; in any other direction the relation is different. Moreover, friction of the weight upon the plane has much to do with the relation of power to weight. The law would be quite true only when friction did not exist, a case which never occurs in practice. If the weight is to be balanced on the plane, then friction helps the power to do it; but if the weight is to be moved up the plane, friction is a hindrance instead of a help.

Explain Fig. 113.—This picture, Fig. 113, shows how barrels are drawn up from or let down into a cellar. It is a case of the inclined plane which you can easily understand and explain without further help.

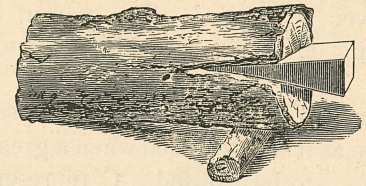
Fig. 113.



How does a woodman sometimes split his blocks?—When blocks of wood are to be split, a smaller block of wood or metal, made thick at one end and tapering to an

edge at the other, is driven into the end of it, as shown in Fig. 114. The tapering block is called a *wedge.*

Fig. 114.



What are the power and weight in this case?—The energy of the woodman's blows upon the back of the wedge is the *power;* the cohesion of the wood is the *weight*, and it is not easy to find the relation between these two forces. Hence we cannot here state any *law* according to which the ratio of power and weight, when they balance each other, can be found.

What familiar instruments act on the principle of the wedge?—The chisel of the carpenter is a wedge; so is the blade of a pocket-knife; each having a sharp edge, and being thicker at a distance from it. The chisel is usually driven by blows; the knife urged by pressure; but the cohesion of the wood is the resistance, or the *weight* to be overcome by both. All cutting and piercing instruments are different forms of the wedge.

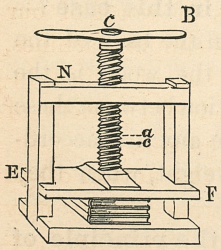
Describe the screw.—The screw consists of a cylinder having a spiral groove cut around its circumference. The small screw used by carpenters for joining the parts of their work, on a small scale illustrates this arrangement. When the screw is to be used as a machine, the cylinder is made larger, sometimes a few inches, sometimes several inches in diameter. The projecting edges left between the parts of the spiral groove are called *threads*, and the screw works through an opening in a firm block having a spiral groove cut upon its interior surface into which these

threads just fit. This block is called the *nut*, or sometimes the *concave screw.*

The top of the screw is called its *head:* it is the part to which the power is applied. The power is generally applied by means of a lever reaching outward from the head.

Explain Fig. 115.—This cut represents a screw set in a firm framework, as it is often used when a great pressure is to be exerted. C represents the head of the screw, and B the lever by which it can be turned. The block N through which the screw works is the nut.

Fig. 115.



When the screw is turned by the lever it advances through the nut and pushes the movable block E F down upon the body to be pressed. An enormous pressure may, in this way, be exerted upon this body.

The *power* is applied at B, and the pressure exerted is the *weight.*

What is the relation between the power and weight?—As the screw is turned the power at B must travel around a large circle, and when it has gone once around, the screw will have advanced through the nut a distance *a c*, the distance between two contiguous parts of the thread. Now it is found that the weight will be as many times greater than the power, as the circumference through which the power travels is times greater than this little distance *a c.* In other words, the law may be stated: "The power and weight will balance, when the power is to the weight as the distance between two contiguous threads is to the circumference in which the power moves."

How many machines have now been described?—We have now described *six simple machines* by which

weights may be lifted or resistance overcome. Let us bring their names together.

The Lever.	The Inclined plane.
" Wheel and axle.	" Wedge.
" Pulley.	" Screw.

There are no others. All forms of machinery are made by combining these six. Just as when you learned the twenty-six letters of the alphabet you possessed all the characters used in the many thousands of words of our language, so, having learned of these six simple machines, you have learned of all the elements out of which ingenious men have contrived the wonderful variety of machinery to be found among civilized nations.

What one principle holds good in the action of all these machines?—A *small power* acting *swiftly* may put a *large weight* in *slow motion;* or a *great power* acting *slowly* may put a *small weight* in *rapid motion.*

This law holds good in all forms of machinery, what is lacking in *force* must be made up in *velocity.* And in just this lies the advantage of using machinery. It helps man to transform *velocity* into *power* to overcome resistance. No power can be created by it, and wherever power is gained it is *bought* and *paid for* in *velocity.*

By what agents is power to move machinery exerted?—Animals, water, wind, and steam are the agents or powers most commonly applied to move machinery. Men or horses, by means of pulleys or wheels, may be seen lifting stones where large buildings are being erected. Saw-mills and flouring-mills are often worked by "water power" acting upon the circumference of large wheels. Wind-mills for pumping water and for other purposes are turned by the wind, while in the steam-engine and all the vast machinery in the arts moved by it, the motive power is steam.

What is meant by the term "Horse-Power"?—The term *horse-power* is used in estimating the effect which a steam-engine or other machine can produce. The term *has no reference to the animal whose name is used:* it simply means a certain amount of work. A power to lift 33,000 lbs. through 1 foot in 1 minute is a "horse-power." So when an engine is described as an engine of "10 horse power," we understand that it is able to do a work equal to that of lifting 10 times 33,000 lbs. 1 foot in 1 minute.

THE STEAM-ENGINE.

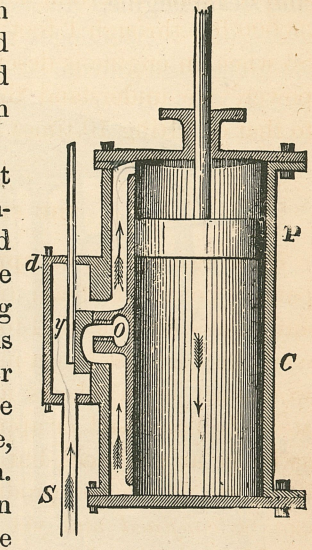
How can steam be applied to machinery?—The expansive power of steam (p. 142) was known long before any means were devised to use it in machinery. Animals could be harnessed to a machine easily: water and wind would act upon wheels and turn them, but how could *steam* be harnessed or applied? In the open air steam is as feeble as an insect, but when confined in a close vessel its efforts to expand produce enormous pressures. If it can be *confined* and yet be properly brought against a machine, the machine will be put in motion. This is accomplished in the *steam-engine.*

How is this accomplished?—For this purpose a cylinder is provided, having a piston fitting its interior nicely, and able to move smoothly from one end to the other back and forth. Steam is made to enter the cylinder first at one end of the cylinder, then at the other, and the pressure of the steam behind the piston knocks it back and forth from end to end with enormous force.

Explain Fig. 116.—Fig. 116 will illustrate this brief description. C represents the cylinder, and P the piston which can move freely from end to end. S represents the pipe through which the steam comes from the boiler. It enters the box shown by the open space, *y*, and the steam

passes from there in a direction shown by the upper arrow, and enters the cylinder at the top. Once in the cylinder it expands against the piston and pushes it down, the old and useless steam below, passing at the same time through an opening at the bottom, and thence up to the space O, and away through a pipe not shown in the cut.

Fig. 116.



When the piston has almost reached the bottom of the cylinder, the block *y slides up*, and covers the passage leading to the top, but uncovers the one leading to the bottom. The steam is then forced through the lower passage to the bottom of the cylinder, and, expanding there, drives the piston to the top again.

The block *y* then slides down and opens the upper passage: the steam goes to the top behind the piston and drives it down. The block *y* then slides up again and opens the lower passage: the steam goes to the bottom behind the piston, and drives it to the top.

You see that by the *slide valve*, *y*, the steam goes first to one end of the cylinder, then to the other, and thus drives the piston P back and forth.

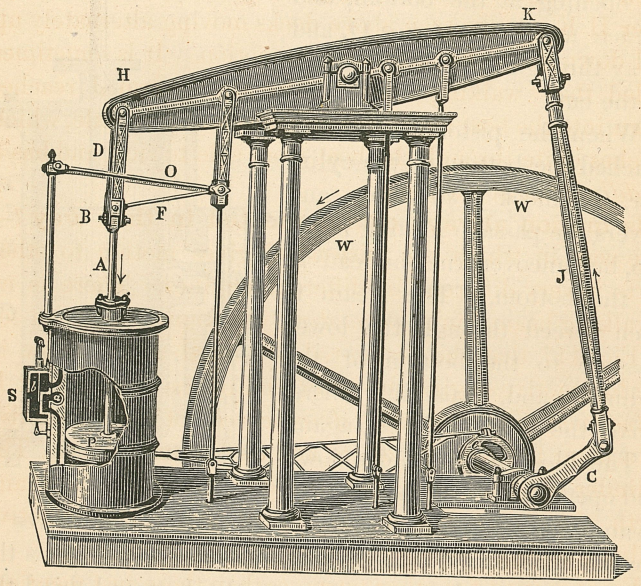
Now this piston P has a rod firmly fastened to it which reaches up through the top of the cylinder, and which is pushed out and drawn in by the moving piston. It is called the "piston-rod." The *outer end of this piston-rod acts as a power* to move levers or turn cranks, and thus give motion to machinery.

The steam moves the piston, the piston moves the pis-

ton-rod, and the piston-rod gives motion to the machinery outside.

Explain Fig. 117.—The picture, Fig. 117, shows how the piston-rod gives motion to machinery in one form of the steam-engine.

Fig. 117.



In the first place, at the left, we see the cylinder with one side cut away, so that we may see the piston (P) inside. The steam is supposed to be entering the valve-box at S and going to the upper part of the cylinder, pushing the piston down, just as we described when we explained Fig. 116.

The piston-rod A D is fastened to one end of the large and strong lever H K. As the piston goes down it pulls this end of the lever down and throws the other end K, up. When the piston rises in the cylinder the piston-rod pushes the lever end H, up, and throws the other end K, down.

Now as the lever at K goes up and down, it pulls and pushes upon the strong arm J, and in this way turns the crank C. The large wheel W W, fixed upon the axle, will thus be put in motion.

Where may we find engines of this form?—This form of engine is often used on steamboats. The great lever H K may be seen above decks moving alternately up and down when the steamer is in motion. It is sometimes called the "walking-beam." The strong arm J reaches down into the boat and turns an enormous iron axle, which reaches quite through the boat from side to side, and has a *paddle-wheel* at each end.

Is motion always communicated in this way?—The way in which the piston-rod gives motion to other parts is very different in different engines. There is no "walking-beam" in a *locomotive*, you know. You can see in Fig. 117 that the piston-rod is jointed at B. Now in the locomotive engine the outer end of the jointed part D is fastened directly to the "*drive-wheel*" of the locomotive at a point between its centre and its circumference. The cylinder lies horizontal, and as the rod A moves back and forth the "drive-wheel" is turned and the locomotive rolled forward.

Engines used for other purposes than those just mentioned are made in different forms. A visit to some manufactory, where you may see for yourself the construction and action of one of these most wonderful machines, will do more to make you acquainted with its parts and their uses than can be gained from books, even though you study long and faithfully.

What is a high-pressure engine?—Sometimes the steam, after pushing the piston, is made to escape into the air in puffs. This is done in the locomotive engine, and it gives rise to the irregular puffs heard especially when the engine starts. Now this steam must be *pushed* out *against*

the air, which presses with a force of 15 lbs. to the square inch to keep it in the cylinder. The steam which moves the piston must exert force enough to overcome this pressure before it can exert any to move the machinery outside. Its pressure must be at least 15 lbs. to the square inch *higher* than the machinery would otherwise require. On this account the engine is called a *high-pressure* engine.

What is a low-pressure engine?—In other engines the steam, after having moved the piston, is allowed to pass through a pipe into a closed chamber, where, by cold water, it is condensed. The withdrawal and condensation of the steam removes the pressure from in front of the piston, and the force of the steam behind it may be all expended in moving the machinery. Since the steam has less work to do, it can do it with less pressure than in the high-pressure engine, and this form is on this account called the *low-pressure* engine.

REVIEW.

SUMMARY OF PRINCIPLES.

THE PROPERTIES OF MATTER.

THE PROPERTIES OF MATTER are of two kinds, viz.:

Physical properties—those which a body may show without undergoing any change in its nature, and

Chemical properties—those which a body cannot show without undergoing a change in its nature.

MATTER exists as Masses—separate bodies of indefinite size and weight; Molecules—particles which cannot be divided without changing them into other forms of matter; Atoms—the smallest particles of an element which can exist in a molecule.

NATURAL PHILOSOPHY, or PHYSICS, is the science which treats of the physical properties of matter, and explains those phenomena in which there is no change in the nature of substances.

The MASS of a body is the quantity of matter which it contains.

The VOLUME of a body is the space which it occupies. The cubic inch or the cubic centimetre is the unit of volume.

ATTRACTION.

FORCE is that which tends to produce, or to diminish, or in any way to change the motion of a body.

ATTRACTION is the force under whose influence bodies tend to approach each other. It is called Gravitation when it acts between masses, Cohesion when it acts between molecules, Chemical Attraction when it acts between atoms.

GRAVITATION acts upon all bodies and through all distances. Its strength is proportional to the quantity of matter in the bodies exert-

ing it, and inversely proportional to the square of the distance through which it is exerted.

Weight is the pressure caused by the earth's attraction.

The Center of Gravity of a body is the point which if supported the body will be at rest.

The Line of Direction is a line from the center of gravity of a body toward the center of the earth.

A body will fall over unless the line of direction passes through some point in its base.

The lower the center of gravity, and the larger the base on which a body stands, the more difficult it is to overturn it.

COHESION is sometimes called Adhesion, when it acts between molecules of unlike kinds, and Capillary Attraction, when it acts between solids and liquids.

Fluids rise in small tubes and penetrate porous substances by capillary attraction.

The heights to which liquids rise in tubes of various diameters vary inversely as the diameters.

LIQUIDS.

LIQUIDS are bodies in which the molecules are held together by such feeble cohesion that they can move freely among themselves.

Liquids are almost incompressible. Water is compressed .0000503 of its volume by a pressure of fifteen pounds to the square inch.

They are perfectly elastic: on springing back they restore all the force which had been exerted to compress them.

A cubic foot of water at ordinary temperature weighs 62½ lbs.

At any point in a body of water at rest there is pressure exerted equally in all directions.

Hence, the surface of a liquid at rest must be a level surface.

And water must rise to equal heights in all vessels or reservoirs which communicate with one another

Fountains and the system of water-supply for towns illustrate this principle.

The pressure of water upon the bottom of the vessel which contains it is always just proportional to the depth of the liquid.

The shape of the vessel, and consequently the quantity of the water, makes no difference.

Hence a small quantity of water will exert an enormous pressure if it is placed in a small but high tube.

An external pressure upon any part of the surface of a liquid will be transmitted equally to all other parts of the surface.

The hydrostatic press illustrates this principle. It is used when very great pressures are to be exerted through small distances.

GASES.

GASES are bodies in which the molecules are free from cohesion.

All gases are very compressible. Fifteen pounds to the square inch compresses air into half its original volume.

The expansibility of gases is without known limit.

The elasticity of gases is perfect.

All gases have weight. One hundred cubic inches of air at ordinary temperature weighs about 31 grains.

THE ATMOSPHERE exerts pressure, in all directions equally, about 15 lbs. to the square inch, sometimes more and sometimes less.

The barometer is an instrument which shows the variations in pressure of the atmosphere and indicates changes in the weather.

A rising barometer column indicates fair weather; a falling column indicates foul weather.

The barometer is also used to find the heights of mountains.

In the lifting-pump water is raised by the upward pressure of the atmosphere.

In the force-pump water is ejected in a steady stream by the pressure of air condensed in an air-chamber.

In the siphon water is transferred from a vessel by the pressure of the air.

MOTION.

BODIES OF MATTER have no power to change their own condition of rest or motion.

A body at rest would rest forever, or, if in motion, it would continue with the same velocity and in the same direction if it were not acted upon by some force to prevent it. This is the first "law of motion."

A force will cause the same effect whether it act upon a body at rest or already in motion. This is the second "law of motion."

Every action must be followed by an opposite and equal reaction. This is the third "law of motion."

FORCES may be classified as Impulsive, Constant, and Variable.

An Impulsive force acting alone will produce uniform motion.

A Constant force acting alone will produce uniformly accelerated motion.

A Variable force acting alone will produce variable motion.

But if the moving body meet with resistance of air, or of friction, or of other kind, the motion will be modified accordingly.

The force of gravity is the most perfect example of a constant force.

Hence the MOTION OF A FALLING BODY is the most perfect example we have of a uniformly accelerated motion.

All heavy bodies fall with the same velocity: light bodies also, in theory, but the resistance of the air is not so easily overcome by them, and hence their motion is retarded enough to be appreciable.

A body starting from rest will fall about

16 feet in the first second.
3×16 " " next "
5×16 " " third "
7×16 " " fourth "

The distance increases by 2×16 feet in every second of the descent.

This distance, 2×16 or 32 feet, which the motion of a falling body increases every second, is called the ACCELERATION. A more exact value of the acceleration is $32\frac{1}{6}$ feet.

A body will fall about

16 feet in 1 second.
4×16 " in 2 seconds.
9×16 " in 3 "
16×16 " in 4 "

Hence, to find how far a body will fall in any given time, square the number of seconds, and multiply by 16. Or for any uniformly accelerated motion whatever, square the number of seconds, and multiply by *one half the acceleration* in that motion.

The velocity acquired by a falling body at the end of the

1st second is 32 feet.
2d " is 2×32 "
3d " is 3×32 "

Hence, to find the velocity of a falling body at the end of any given time, multiply the number of seconds by 32. Or, for any uniformly accelerated motion whatever, multiply the number of seconds by *the acceleration* in that motion.

If the path of a moving body is a curve, the motion is produced by at least two forces, one of which is constant.

If the directions of these forces make a right angle, the path of the body will be the circumference of a circle.

The force which acts toward the center of the circle is the centripetal force; that which acts at right angles to this is the projectile force.

If the radius of the circle remains the same, the centripetal force and the so-called "centrifugal force" will vary *as the square of the velocity* of the body.

If the velocity of the body remains the same and the radius of its circle changes, the centripetal force and the so-called "centrifugal force" will vary inversely as the radius of the circle.

VIBRATIONS.

Any motion in which a body passes to and fro over the same path is vibration.

THE VIBRATIONS OF A PENDULUM of given length are performed in equal times, *i. e.*, they are isochronous.

The time of one vibration is not affected by the size, or weight, or form, or material of the pendulum; it depends only on the length of the pendulum.

The time for one vibration varies as the square root of the length of the pendulum.

But at different places on the earth the force of gravity is different, and the time of vibration will be shorter where gravity is stronger.

The time of vibration is less and less as the pendulum is carried further and further toward the poles of the earth.

Hence the force of gravity is stronger in higher latitudes than at the equator.

Which shows that the distance to the center of the earth is less in high latitudes than at the equator.

In this way the pendulum shows that the polar diameter of the earth is shorter than the equatorial, and hence that the earth is not a perfect sphere.

The principal use of the pendulum is to measure time

The rate of A VIBRATING CORD or wire depends upon its length, its weight, and its tension.

Other things being equal, the rate of vibration varies inversely as the length of the cord.

Other things being equal, the rate of vibration varies inversely as the square root of the weight of the cord.

Other things being equal, the rate of vibration varies directly as the square root of the tension.

Vibrations occur in other solid bodies, as rods, bells, and plates, in liquids and in gases.

Vibration is transmitted through all elastic media.

The passage of vibration from one part of a medium to another is an *Undulation* or *Wave.*

SOUND.

SOUND is an undulation which can affect the ear. It is produced by the vibrations of the sounding body.

The ear is affected by undulations between the rates of 16 per second and 38,000 per second.

THE VELOCITY of sound is not the same in all media. In air at a temperature of 61° F. it is 1,118 feet a second; in water it is about 4,719 feet a second.

THE LOUDNESS of sound depends upon the amplitude of vibration in the sonorous body.

The loudness or intensity of sound varies inversely as the square of the distance from its source.

Tubes keep the undulations from spreading outward, and thus convey them forward for long distances. For this reason sounds can be heard farther in speaking-tubes.

THE REFLECTION of sound occurs whenever the sound strikes against the surface of an obstacle.

The direction from which the waves enter the ear is always the direction in which the sound is heard.

An echo is heard when sound is reflected from an obstacle at sufficient distance away.

If the reflecting surface is near, the direct and reflected waves are mingled in the ear, and the echo is not distinct or not heard at all.

MUSICAL SOUNDS are undulations made with great regularity and rapidity.

Any noise repeated regularly and rapidly is a continuous and musical tone.

Musical sounds differ in three things, viz.: Pitch, Intensity, and Quality.

Pitch is that which distinguishes sound as being high or low.

Intensity is that which distinguishes sound as being loud or soft.

Quality is that which distinguishes sounds of the same pitch and intensity, but made by different instruments.

Pitch depends on the *rate* of the waves.

Intensity depends on the *amplitude* of the waves.

Quality depends on the *form* of the wave.

The form of a wave varies with the number and relative intensities of the simple waves which combine to produce it.

The sound in stringed instruments is due to the vibration of cords or wires.

The sound in wind instruments is due to the vibration of air in tubes or pipes.

The correct pitch of the sounds of stringed instruments is secured by using strings of different lengths and different weights, and stretching them with different tensions.

The correct pitch of the sounds in wind instruments is secured by using pipes of different lengths, or by the use of "keys" by which the vibrating air-column is shortened or lengthened.

LIGHT.

LIGHT goes in straight lines and in all directions from a luminous body.

An opaque body intercepts light and "casts a shadow," because the light cannot bend around its edges to fill the space behind it.

A shadow consists of an umbra and a penumbra, because the light from different points of the luminous body makes as many different shadows which overlap one another.

THE VELOCITY of light is about 186,000 miles a second.

THE INTENSITY of light varies inversely as the square of the distance from its source.

REFLECTION of light occurs whenever rays fall against the surface of another medium.

The law of reflection states that the angles of incidence and reflection are equal and in the same plane.

We see objects by light which comes from them into our eyes.

In the case of every non-luminous body only reflected light can come from them; we see such bodies by reflected light.

MIRRORS are of three varieties, viz.: Plane, Concave, and Convex.

We see objects in the direction from which the light which comes from them enters our eyes.

When the light which enters the eye has been reflected by a mirror, we see an image of the object from which the light started.

AN IMAGE by reflection is to the eye what an echo is to the ear.

The image formed by a plane mirror is always behind the mirror; it is the same in size as the object, and erect.

A concave mirror collects rays of light by reflection.

The character of the image by a concave mirror depends on the position of the object.

If the object is very near to the mirror, the image will be seen behind it, larger than the object, and erect.

But let the object be between the principal focus and the center of curvature of the mirror, and the image will be formed in front of it, further away than the center of curvature; it will be larger than the object, and inverted.

And if the object is beyond the center of curvature of the mirror, the image will be between the center of curvature and the focus; it will be smaller than the object, and inverted.

The image formed by a convex mirror is always behind the mirror, always erect, and always smaller than the object.

REFRACTION of light occurs when rays enter another medium.

If light enters a denser medium, the angle of refraction is less than the angle of incidence.

If light enters a rarer medium, the angle of refraction is greater than the angle of incidence.

LENSES are instruments used to refract light. They are of two classes, viz.: Convex and Concave.

All forms of convex lenses collect the rays which pass through them, while all forms of concave lenses separate the rays which pass through them.

Since we see an object in the direction from which the rays of light coming from it enter the eye, and since lenses bend the light that comes through them, an object seen through a lens will never be seen in its true place. In fact, we can never really see the object itself through a lens; we always see its image.

THE IMAGE formed by a concave lens will always be on the same side of the lens as the object, always smaller than the object, and erect.

The image formed by a convex lens will differ according to the place of the object.

If the object is at a distance from the lens less than its focal distance, the image will be on the same side of the lens, larger than the object, and erect.

If the object be at a distance just equal to twice the focal length of the lens, the image will be on the other side, just equal to the object in size, but inverted.

If the object is between once and twice the focal length of the lens away, the image will be further away on the other side of the lens, larger than the object, and inverted.

If the object is more than twice the focal distance from the lens, the image will be at less than twice the focal distance on the other side of the lens, smaller than the object, and inverted.

COLORS are produced by decomposing white light.

The solar spectrum is obtained by passing a beam of sunlight through a prism. It is usually described as consisting of seven primary colors, viz.: Red, Orange, Yellow, Green, Blue, Indigo and Violet. This is the order of their refrangibility, the red being bent least.

These colors may be reunited in various ways, and in whatever way it is done the result is white light.

No colors can exist in nature or in art except these colors of the spectrum, or such as may be obtained by combining two or more of them in different proportions.

The color of any body is simply that part of the white light which its surface can reflect.

Thus the color of a body is due to the decomposition of the light which falls upon it. At its surface white light is divided into two colored parts; one part is reflected, the other absorbed.

The rainbow is produced by the action of drops of water upon sunlight; they decompose it, and produce the colors of the spectrum.

THE MICROSCOPE is an instrument by which we are able to view the magnified images of minute objects. It is either simple or compound.

The simple microscope is a single double convex lens. The object is placed at a distance just a little less than the focal distance of the lens.

The shorter the focal distance of the lens the greater is the magnifying power it possesses.

The compound microscope consists of two convex lenses, one called the object-glass, or *objective*, and the other the eye-glass, or *eye-piece*. The object is placed at a distance just a little greater than the focal length of the objective. An enlarged image is formed, and the eye piece enables the observer to see a magnified image of this image.

THE TELESCOPE is an instrument by which the images of distant objects may be made near the eye.

Telescopes made with lenses are called Refracting Telescopes; those with mirrors are called Reflecting Telescopes.

The refractor contains an object-glass, by which a small image of the distant object is made, and an eye-piece, by which the eye is able to view a magnified image of this image.

This second image is smaller than the object itself, but it is larger than the distant object appears to be when seen by the naked eye.

HEAT.

HEAT emanates from the sun and stars. The sun is the chief source of heat. The stars are other suns, but so distant that their heat is detected with difficulty.

Among other sources of heat are chemical actions, such as combustion, and mechanical actions, such as friction and blows.

All bodies are giving off heat, and at the same time receiving heat from all others.

When bodies are of different temperatures, the warmer gives off more than it receives, and becomes colder, while the colder receives more than it gives, and becomes warmer.

For this reason all bodies in a room together soon have the same temperature.

THE COMMUNICATION OF HEAT from one thing to another is affected by Radiation, Conduction, and Convection.

By radiation, when heat passes in straight lines, in all directions, into space.

By conduction, when heat travels step by step from molecule to molecule in a mass or in masses in contact.

By convection, when heat is carried by currents set up in the body receiving it.

RADIANT HEAT is an undulation like light, and travels with the same velocity as light—about 186,000 miles a second.

Bodies which absorb heat will also radiate it equally well.

Bodies which reflect heat will absorb it poorly, and also radiate it poorly.

Rough and dark colored surfaces are the best to absorb heat and the best to radiate it.

The property of a substance to conduct heat is called conductivity.

CONDUCTIVITY is greater in solids than in liquids, and greater in liquids than in gases.

Among solid bodies metals are the best conductors. But each metal has its own specific rate of conducting heat.

EXPANSION is one of the effects of heat. Gases are expanded most, liquids less, and solids least by the same quantity of heat.

All gases expand alike, increasing just $\frac{1}{273}$ of their volume at 0° C. for each successive degree of heat applied.

But each liquid has a different rate of expansion. Moreover, the rate is not uniform in the same liquid.

Every solid also has a different rate, but its expansion is sensibly uniform.

Water at its freezing temperature is an exception to the law, for, if heated, it contracts. When the temperature has reached 4° C. (39° F.) water expands when heated, in obedience to the law.

MELTING, or the liquefaction of solids, is another effect of heat. Every solid has its own melting point.

Liquids are substances whose melting points are below the ordinary temperature of the air.

BOILING, or the vaporization of liquids, is the third effect of heat. Every liquid has its own boiling point.

The boiling point of a liquid is raised by bringing a pressure to bear upon the liquid, and lowered by diminishing the pressure.

The boiling point of water is 100° C. or 212° F., under the ordinary pressure of an atmosphere—15 lbs. to the square inch.

Steam is able to exert the same amount of pressure as is exerted on the water from which it is formed. By boiling water under great pressure great steam power may be generated.

Heat is absorbed whenever water becomes steam; the same amount of heat is given out whenever the steam is again condensed into water.

TEMPERATURE is indicated by instruments called thermometers.

There are three varieties of mercurial thermometer, viz.: Centigrade, Fahrenheit, and Réaumur. They differ only in the graduation of their scales.

In Centigrade (C.) the melting point of ice is the 0 of the scale, and the boiling point of water is 100. In Fahrenheit's (F.) the melting point of ice is 32° above 0, and the boiling point of water is 212. In Réaumur's (R.) the melting point of ice is 0, and the boiling point of water is 80.

The difference between the melting point of ice and the boiling point of water is 100° Centigrade, 212° Fahrenheit, 80° Réaumur. Hence

$$5° \text{ C.} = 9° \text{ F.} = 4° \text{ R.}$$

To change C.° to F.° we have $\text{F.}° = \frac{9}{5}\text{ C.} + 32$.
To change F.° to C.° " " $\text{C.}° = \frac{5}{9}(\text{F.}° - 32)$.
To change F.° to R.° " " $\text{R.}° = \frac{4}{9}(\text{F.}° - 32)$.

MAGNETISM.

MAGNETS are bodies of iron or steel which are able to attract iron in preference to other metals.

The attraction of a magnet is most powerful at points very near to its ends. These points are distinguished as the north and the south poles.

The magnet is affected by the earth. If a magnetic needle be free to move it will come to rest always with its poles pointing nearly north and south.

And if the needle is free to move up and down, as well as sidewise, its north pole will not only point northward but also obliquely downward. South of the earth's equator the south pole is the one that dips.

Magnetism shows itself not only by attraction but by repulsion also.

The law states that poles of the same name repel one another, while poles of different names attract.

A magnet will impart magnetism to iron or steel brought near it. This action is called induction.

The law states that either pole induces magnetism of the opposite name in the adjacent part of the iron.

ELECTRICITY BY FRICTION.

ELECTRICITY is produced by the friction of two substances.

It shows its presence by attracting and repelling light bodies. Any instrument for detecting its presence is called an electroscope. An instrument to measure its energy is called an electrometer.

Electricity is of two kinds, viz.: Positive and Negative.

The law states that electricities of like names repel one another, while electricities of unlike names attract.

The metals are the best conductors of electricity. But they are not all equally good. Each metal has its own peculiar conductivity.

The electricity of an excited body resides exclusively on its surface.

A pointed conductor cannot be charged with electricity. And a pointed conductor which is in communication with the earth will discharge the electricity of any charged body near it.

On this principle "lightning-rods" are used to protect buildings from strokes of lightning.

LIGHTNING is the light produced by the discharge of electricity between two clouds which are in opposite electrical conditions, or between the earth and a cloud, these also being charged with opposite kinds of electricity.

Thunder is the sudden and intense sound-wave produced by the action of the electric discharge on the air through which it passes.

The identity of lightning and frictional electricity was demonstrated by Franklin in his memorable kite experiment.

INDUCTION is the action of a charged body upon conductors separated from it by non-conducting substance.

Both kinds of electricity are developed on the surface of an insulated conductor by induction.

In a series of polarized bodies, the ends which are near together are in unlike conditions, positive and negative.

THE LEYDEN JAR is an apparatus for accumulating electricity by induction.

Any two conducting surfaces separated by a sheet of non-conducting material is in effect a Leyden Jar.

The jar is charged by bringing one of its surfaces, which must be insulated, into communication with a source of electricity while the other surface is in communication with the earth.

The jar is discharged by making communication between its two surfaces.

The Holtz machine is an instrument in which a glass plate, rotating near to the surface of a stationary plate having two sectors oppositely electrified, furnishes a continuous supply of electricity by induction.

ELECTRICITY BY CHEMICAL ACTION.

CHEMICAL ACTION is any action by which the nature of bodies is changed. The electrical condition of the bodies is changed by any chemical action taking place in them.

The voltaic circuit is the simplest form of an apparatus for generating electricity by chemical action. Any two metals with a fluid between them which can act chemically upon one more than upon the other is a voltaic or simple circuit.

BATTERIES are more powerful forms of apparatus for the same purpose.

The power of a battery may be increased by joining several simple circuits or "cells" together. This may be done in two ways.

The cells may be joined "in series," that is, the carbon or + pole of one with the zinc or − pole of the next, and so on, alternating + and −, to the end, or

They may be joined, the carbon or + pole of one cell with the carbon or positive pole of the next, and so all the positive poles together and all the negative poles together.

The energy of the electricity will be very much greater in a battery coupled in series than if coupled the other way, but the quantity of electricity will be less.

Hence, where great resistance is to be overcome the battery "in series" is best; when great quantity is needed, plates of the same name should be joined.

POTENTIAL is the term used to describe that difference in the electrical condition of two things which enables electricity to flow from one to the other.

The electro-motive force is that which urges electricity through the circuit.

No substance is a perfect conductor of electricity. Good conductors are said to offer little resistance. Resistance is the opposition which a conductor offers to the passage of electricity.

The strength of current, or intensity, is the power of a current to overcome resistance.

The strength of current is always equal to the electromotive force divided by the resistance. This is OHM'S LAW.

THE ELECTRICITY USED UP in overcoming resistance is converted into heat. This is illustrated in the combustion of fine iron wire stretched between the poles of a strong battery.

A small rod of carbon, or a platinum wire, in the circuit of a powerful battery, will be heated to intense whiteness. This is producing electric light by incandescence. Many forms of electric lamp act on this principle.

If the poles of a powerful battery are tipped with carbon and brought together, they may be separated a little distance without breaking the circuit. The space between will be bridged with an arc of blinding light. Many forms of electric lamp are constructed on this principle.

A CURRENT of electricity when passed through water decomposes it; hydrogen and oxygen gases are the constituents set free.

Many other compounds are decomposed by the current. Such are called Electrolytes, and the process is called Electrolysis.

The constituent which appears at the positive pole of the battery is called the electro-negative constituent of the compound; that which appears at the negative pole is called the electro-positive constituent.

ELECTRO-MAGNETISM.

IF A CURRENT OF ELECTRICITY PASSES AROUND A BAR OF IRON it renders the bar a magnet. A bar of soft iron will lose its magnetism as soon as the circuit is opened, but if the bar be of hard iron or steel the magnetism will be permanent.

If the current be sent around the bar in the opposite direction, the polarity of the bar is changed; the end which was the north pole becomes the south pole, and that which was the south pole becomes the north pole.

An electro magnet is a bar of soft iron enclosed in a coil of wire, the ends of which may be joined to the poles of a battery. The coil of wire is called a helix.

An electro-magnet in one city and a battery in another may be connected by wire, and the iron will become a magnet whenever the battery circuit is closed, and lose its magnetism whenever the circuit is opened.

In this case the electro-magnet will alternately attract and release an armature in front of its poles if the circuit be closed and opened in succession.

The electric telegraph is an application of these principles.

LET A WIRE lie just above a magnetic needle and parallel to it when at rest, but not touching it; then if a current of electricity is sent along the wire from south to north, the north pole of the needle will be thrown around toward the west.

If the wire lies below the needle, the current must go from north to south in order to turn the north pole in the same direction as before.

Let the current pass quite around the needle lengthwise, and the needle will swing further than in the other cases, and by winding many times around the effect of the current will be increased.

Send the current through the coil in the other direction, and the north pole of the needle will move to the east.

The motion of the needle shows the presence of an electric current.

An instrument with which to detect or measure a current of electricity is called a Galvanometer. The galvanometer consists of a sensitive magnetic needle so fixed that it can swing freely inside a coil of wire.

INDUCTION.

IF TWO WIRES LIE SIDE BY SIDE, not touching each other, and a current of electricity be sent through one, a current will pass through the other also, but in the opposite direction. This induced current will last only for a moment, just when the current from the battery begins.

Let the battery circuit be opened, and another current will at that moment flow through the other wire in the same direction as the battery current.

The first of these induced currents is called the inverse current, because its direction is opposite to that of the battery current which induces it; the second is called the direct current, because its direction is the same as that of the battery current.

The wire carrying the battery current is called the Primary, and the other is called the Secondary.

If the primary is a coil of large copper wire, and the secondary is a coil of fine copper wire of great length, the induced currents are very strong.

Induction coils are made on these principles, and yield electricity of great intensity. The spark from the battery can with difficulty be detected; that from the induction coil attached to the same battery may be able to leap through several inches of air.

IF THE POLE OF A MAGNET be thrust into a helix, a current of electricity will be set up in the wire. If the pole be taken out of the helix, a second current will traverse the wire in the direction opposite to that of the first.

If a magnet be wound with a coil of wire, any increase or diminution of its strength will produce a current of electricity through the coil.

The strength of a magnet will be alternately increased and diminished by simply moving a piece of soft iron toward and away from its pole.

An undulatory current can thus be sent long distances through a wire by simply vibrating a sheet of soft iron in front of one pole of a magnet which is surrounded by a coil of the wire.

The Bell telephone is constructed on these principles.

MACHINERY.

THERE ARE SIX SIMPLE MACHINES, viz.: the Lever, the Wheel and Axle, the Pulley, the Inclined Plane, the Screw, and the Wedge.

All forms of machinery are different combinations of these simple forms.

A "law of equilibrium" is a statement of the relation between the power and the weight when they just balance each other in a machine.

The law of equilibrium for the lever states that the power and weight will be in equilibrium when they are to each other inversely as their distances from the fulcrum.

For the wheel and axle the law of equilibrium states, that the power and weight will be in equilibrium when the power is to the weight as the radius of the axle is to the radius of the wheel.

For the movable pulley with a single rope the law states, that the power and weight will balance each other when the power is equal to the weight divided by the number of branches of the rope which supports it.

For the inclined plane there are two cases, viz.: the power may act parallel to the length of the plane, or the power may act parallel to the base of the plane. In the first case, the power and weight will balance each other when the power is to the weight as the height of the plane is to the length of it. In the second case, the power and weight will balance each other when the power is to the weight as the height of the plane is to its base.

For the screw the law states, that the power and weight will balance when the power is to the weight as the distance between two contiguous threads is to the circumference of the circle in which the weight moves.

A wedge is usually driven by blows, and as it is not easy to determine the relation between a blow and the resistance which it overcomes, we do not state a law of equilibrium.

Whenever power and weight balance each other, they are doing exactly equal amounts of work. A small power acting rapidly will do as much work as a larger weight acting more slowly.

Hence the truth of the old mechanical proverb: "What is gained in power is lost in time."

To keep a machine in action, the power must be a little greater than what the law of equilibrum for the machine requires, owing to friction and other resistances.

Such resistances are always present; they cannot be abolished, and hence a machine must stop work unless energy is continually supplied.

Hence the folly of all schemes for "perpetual motion." No machine can create energy; a machine can only apply the energy which is given to it, and it must stop work the moment its supply of energy is exhausted.

ENERGY.

WORK is the overcoming of any kind of resistance.

The unit of work is that which is done in lifting one pound to the height of one foot. This is called the *foot-pound*. The French unit is the *Ki'ogram-meter*.

ENERGY is the ability to do work To overcome resistance of any kind requires the expenditure of energy.

The energy of a moving body varies directly as its mass and the square of its velocity.

To compute the energy of any moving body, multiply the square of its velocity (feet per second) by its mass in pounds) and divide the product by $64\frac{1}{3}$.

Energy is of two types, viz.: Kinetic energy, which is the energy of a body due to its motion, and Potential energy, which is the energy of a body due to its separation from another which attracts it.

There are several varieties of energy, viz.: Mechanical, Molecular, Chemical, Radiant, and Electrical

Energy may be transmitted from one body to another; it is whenever a moving body meets an obstacle of any kind.

Energy may be transmuted from one variety into another; it is whenever any form of energy disappears.

The "law of conservation states that energy may be transmitted or transmuted, but cannot be annihilated or changed in quantity.

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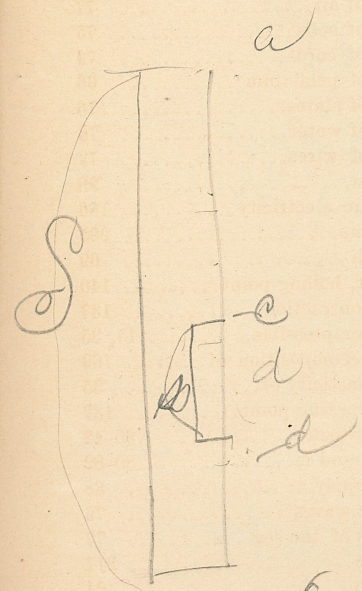
t = time in seconds.

g = 32,16 the increment of velocity

v = velocity at the end of ~~any~~ second.

s = space fallen each second.

S = total space ~~through~~ in any ~~#~~ of secs.



$v = \frac{1}{2} g (2t - 1)$ (4) second

$s = \frac{1}{2} g (2t - 1)$ (5) second

$S = \frac{1}{2} g (t)^2$ (8 secs) seconds

a + B be 2 pendulums

2√a will be to √B as

the time a is B. Time

√a : √B :: inversely the beats of

B is to the number of

beats of a. Beats

---

a : b :: √time a : √time b

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a : b :: inversely √beats of B : √beats of B

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